APPENDIX I ECOSYSTEM CONCEPTUAL MODELS

Sierra Nevada Network

DRAFT – December 2006

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Appendix I. Sierra Nevada Network Ecosystem Conceptual Models
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APPENDIX I. SIERRA NEVADA NETWORK ECOSYSTEM CONCEPTUAL MODELS DRAFT – DECEMBER 2006

Introduction

Conceptual models are important elements in the design of scientifically sound monitoring programs for the management of ecological systems. Conceptual models assist us in organizing information and reducing ecosystem complexity to a manageable set of key components and processes. A conceptual ecosystem model is a visual or narrative summary that describes the important components and interactions within an ecosystem. Developing conceptual models facilitates understanding of how physical, chemical and biological elements of a monitoring program interact, promotes integration and communication among scientists and managers from different disciplines, and informs the choice of indicators (Gross 2003). The models inform the selection of indicators and design of monitoring protocols in addition to providing a basis for interpreting monitoring data.

This appendix is a ***work in progress***, and its purpose is to present current versions of our overview, system, and detailed models that provide context for the vital signs we selected for long-term monitoring. For our final Phase III report, we intend to further develop, organize, and standardize our models and accompanying text so that they present a stronger foundation for our monitoring program. We also intend to incorporate more explicitly the concepts of spatial and temporal scale into our presentation of Sierra Nevada ecosystem models.

Purpose of Models

Conceptual models have served the following objectives in development of our monitoring program:

- Formalize current understanding of ecosystem structure and function as well as relationships among ecosystem components at various levels of organization (landscape, community, watershed, population).
- Highlight effects of important drivers and stressors on park resources and ecosystem processes.
- Identify and articulate relations among ecosystem attributes of interest and indicators.
- Facilitate communication among participants in the iterative process of vital signs identification, prioritization, selection, and protocol development.

As the Network progresses toward implementation of vital signs monitoring, the models should inform our thinking about sample design, facilitate integration and synthesis of data, and serve as communication tools about the program (Gross 2005). We hope that we can develop models that assist us in communicating connections between management decisions and information gained from monitoring, such as identification of threshold conditions that could trigger a management action.

Approach

Development of models for the Sierra Nevada Network began with the Science Committee during the planning of Phases I and II of vital signs monitoring. These models helped to inform the vital signs prioritization at a March 2005 workshop, and subsequently, the Science Committee's selection of a subset of vital signs for protocol development. As the Network now focuses on protocol development and implementation of vital signs monitoring, this stage of our models highlights the focal systems, drivers, components, and processes that either comprise or closely relate to the vital signs we have selected. The models presented here are developed from local knowledge of NPS and USGS staff members, published literature, and ideas presented by other NPS network vital signs monitoring plans.

While we are still a long way from adequately incorporating concepts of spatial and temporal scale in our models, we do attempt to organize our models into a hierarchical framework that includes overview, systems, and detailed models (Table I- 1).

Table I- 1. Summary of conceptual models and location in document.

	Model Name	Location
Overview	General Ecosystem Model	Appendix I
	Landscape Exchange	Chapter 2, Appendix I
	Stressors and Interactions	Appendix I
	Focal Systems	Chapter 2 and Appendix I
System	Atmospheric	Appendix I
	Landscape Dynamics	Appendix I
	Forest	Appendix I
	Aquatic	Appendix I
	Meadows/Wetlands	Appendix I
Detailed	Nitrogen Deposition	Appendix I
	Fire Regimes	Appendix I
	Plant Community Invasibility	Appendix I
	Hydrology	Appendix I
	Aquatic biota	Appendix I
	Lakes	To be developed – FY2007
	Streams and Rivers	To be developed – FY2007
	Mountain Yellow-legged Frog	Appendix I
	Meadow Invertebrates	Appendix I
	Bird Populations	Appendix I

Overview Models

We use four overview models to 1) highlight the ecosystem factors that interact with processes to structure the physical environment and its biotic communities; 2) illustrate inputs and outputs that affect the Sierra Nevada landscapes; 3) highlight the most important stressors for the Sierra Nevada and their interactions; and 4) highlight the focal systems and processes we target for monitoring.

General Ecosystem Model

The environment in the Sierra Nevada is a function of the interactions among the physical factors of topography, geology, regional climate, and the available organisms (Figure I-1). These factors are inextricably linked to the abiotic and biotic ecosystem components including local climate, hydrology, soils, vegetation, and wildlife. The distribution and abundance of the biotic communities in the network parks are directly influenced by these interactions.

Implicit in Figure I- 1 are the processes that shape the physical environment and influence the distribution and abundance of organisms. The processes include processes of weathering, mineralization, erosion, and decomposition that affect soil and water quality; climate-driven processes of change that include fire, flooding, avalanches, and hillslope sediment transport; and biotic processes such as reproduction, growth, mortality, predation, herbivory, and pollination.

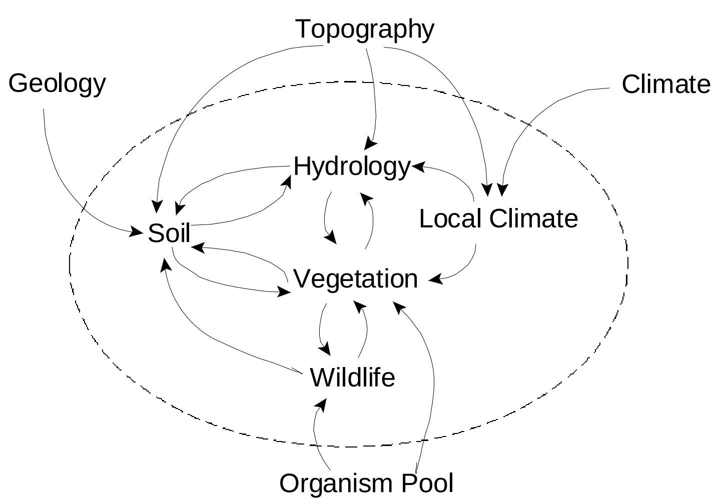


Figure I- 1. General ecosystem model for Sierra Nevada. Topography, climate, geology, and organisms interact with each other and ecosystem processes to determine habitat quality and the resulting biotic community distribution, structure, composition, and function. Model courtesy of J. van Wagtendonk, USGS-Western Ecological Research Station, Yosemite National Park.

Landscape Exchange Model

A landscape can be thought of as an "open" system that can exchange energy, materials, and organisms with its surroundings. In this context, broad-scale processes *constrain* these exchanges among landscapes. For example, the regional climate could be considered a constraint on the Sierra Nevada landscape. Park "boundaries" are mostly arbitrary delimitations with respect to atmospheric, hydrologic, and other ecosystem processes.

The extent (area) of a landscape influences the "openness" of a landscape. For example, in the Sierra Nevada Network—does Devils Postpile National Monument have special needs or problems because it is a smaller unit? Will a non-native species or a natural disturbance disproportionately affect the monument? Landscapes of small extent may be more profoundly influenced by their surroundings than those of larger extents, which may be able to compensate for disturbances in one area within the park.

The major interactions between a Sierra Nevada landscape or park and the surrounding landscape are illustrated in Figure I- 2. Many of these exchanges are common to all Sierra Nevada landscapes regardless of shape, size, or locality. Some external inputs are little influenced by the parks themselves. These include meteorological inputs (e.g., precipitation, solar radiation, water vapor, CO_2), and airborne pollutants (e.g., Nitrogen, persistent organic pollutants).

The Sierra Nevada landscape exchanges energy, materials, organisms, and processes with the larger landscape within which it is embedded. For example, birds and other animals freely cross the boundary between park and non-park habitats. Fire can propagate into or out of a park unit. Non-native invasive species that are present outside the boundaries can be transported into a park area by wind, animals, or human activities. River flows can originate from a park and cross the boundary to lower elevations, or may only flow through a park and therefore not encompass the uppermost reach of the watershed (e.g., San Joaquin River through Devils Postpile). Implications of these exchanges (of materials, organisms, etc.) for park resources need to be explored and related to management concerns. Although we can't control what comes in, we can monitor effects and mitigate to some extent through thoughtful management.

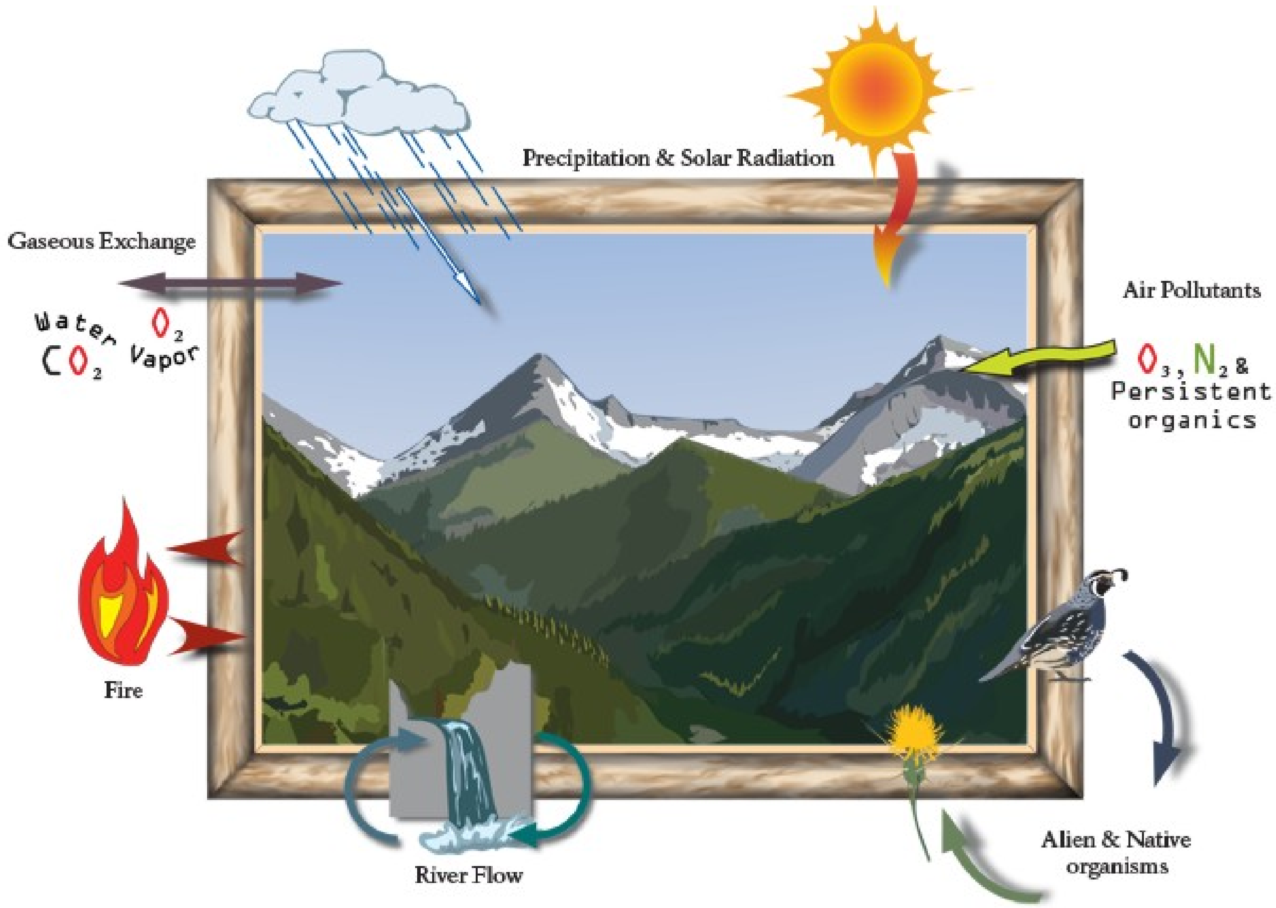


Figure I- 2: Major inputs and exchange of energy, materials, organisms, and processes for a given Sierra Nevada landscape and its physical surroundings. Illustration by Justin Hofman.

Sierra Nevada Stressors Model

Network park managers and researchers, using well-considered professional judgment, a substantial supporting body of research, and findings from the Sierra Nevada Ecosystem Project (SNEP 1996, Sequoia And Kings Canyon National Parks 1999b), have identified five important systemic stressors posing the greatest threat to Sierra Nevada Network parks. (These stressors are discussed in more detail in Chapter 1 of the Draft Phase III Vital Signs Monitoring Plan.) To summarize here, five systemic stressors currently pose the greatest threat to Sierra Nevada Network parks:

1. rapid anthropogenic climate change
2. altered fire regimes
3. non-native invasive species
4. air pollution
5. habitat fragmentation and human use

The effects of these systemic stressors on ecosystem biota and processes influenced our selection of Network vital signs, indicators, and measures. While in Chapter 1 we described the individual stressor effects on the ecosystem, we did not emphasize the likely enhancing influences the stressors will have on each other (Figure I- 3).

Climate change may have the greatest potential to affect ecosystems in part because it helps generate associative or synergistic effects which couple with other stressors, particularly—altered fire regime, air pollution, and non-native invasive plants. Climate change can affect critical ecosystem components and processes, including: entire forests and other plant communities; phenology of plants and animals; ranges of disease vectors; precipitation amounts, type and timing of natural events; snowpack; surface water dynamics; and hydrologic processes. Anthropogenic climate change might soon influence all other stressors and become the predominant stressor.

Altered fire regime significantly affects forests and other plant community composition and structure (e.g., increases in forest and shrub density). It can result in shifts in plant and animal species composition, including possible loss of fire-dependent species, and will almost certainly increase the probability of unnaturally severe fire. It influences presence of non-native invasive species, hydrology, water and soil chemistry, biogeochemical cycling and air quality.

Non-native invasive species (plants and animals, including pathogens) can severely alter plant community composition and structure, competition and predation, native plant and animal diversity, fire regime, and soil water dynamics.

Air pollution affects water and soil chemistry, forest population dynamics (e.g., reduced vigor), plant community composition, and may affect wildlife (e.g., endocrine disruption of amphibians). In addition, it may favor non-native plants through nitrogen deposition, and affects fuel availability for fire by affecting plant productivity.

Finally, human use and park fragmentation typically results in: habitat loss, altered fire regime, diversion of water, disruption to wildlife, increases in non-native species invasions and may degrade wilderness values (e.g., dark night sky, natural soundscape).

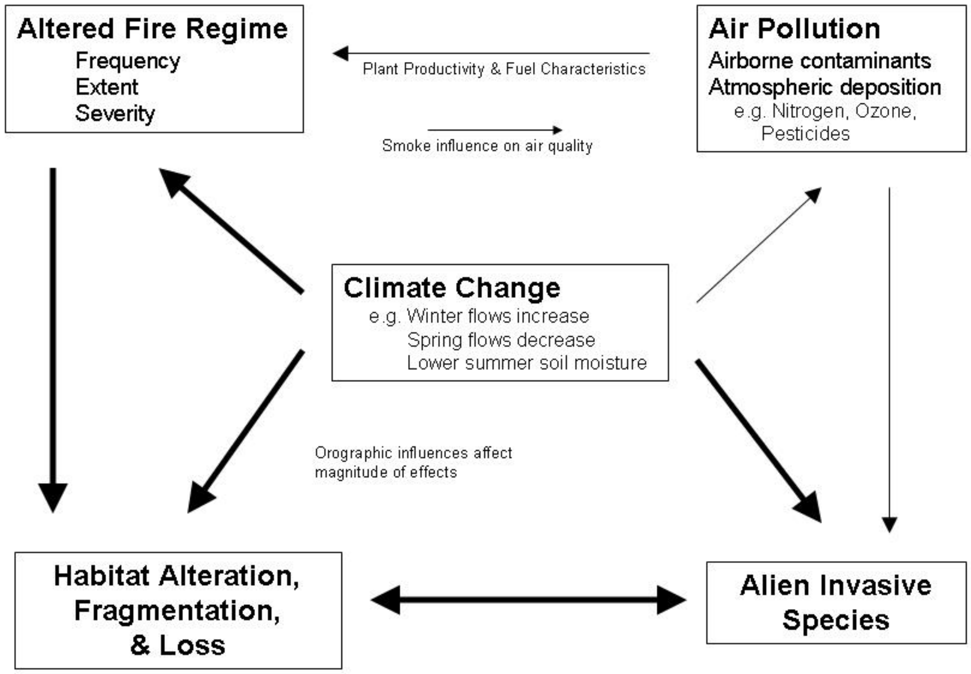


Figure I- 3. Sierra Nevada stressors and associative or synergistic effects.

Focal Systems Model

Through Network workshops, Science Committee meetings and Board of Directors review, we identified components of aquatic, coniferous forest, and meadow/wetland systems as a focus for long-term monitoring due to the ecological significance, sensitivity to major drivers (and anthropogenic stressors), and management priority of these particular systems. The interrelationships among these systems as well as the major drivers that influence them are shown in Figure I- 4.

Major Drivers

This section discusses the major drivers that influence Sierra Nevada landscape dynamics and the focal systems selected for monitoring.

Atmospheric System

The atmospheric system drives weather, and at longer time scales, climate. Climate strongly influences the landscape by determining the flux of both energy (solar radiation) and mass in the form of moisture (rain, snow, water vapor). Stine (1996) generalizes that climate exerts a predominant influence on the components of the Sierra Nevada landscape

- Vegetation (type, biomass, distribution)
- Hydrology (size, distribution, fluctuations, and water quality of lakes and streams)
- Soils (thickness, stability, nutrient capacity)
- Landforms (rates of formation and loss)
- Fire (location, frequency, seasonal timing, intensity and/or severity)

Climate varies spatially and at annual, decadal, centennial and millennial time scales. Numerous paleoecological studies have documented vegetation changes over the past many thousands of years in response to changes in climate. Woolfenden (1996) summarizes that during the Quaternary period of the past 2.4 million years, at least six successive major glacial cycles covered the Sierra Nevada with ice caps and mountain glaciers, filled lake basins in the adjacent deserts, and lowered the elevation limits of plant species. These ice ages were interspersed with shorter warm intervals when habitats expanded into northerly latitudes and tree lines gained elevation. Species responded individualistically to these changes, sometimes assembling into communities with no modern analog (Woolfenden 1996).

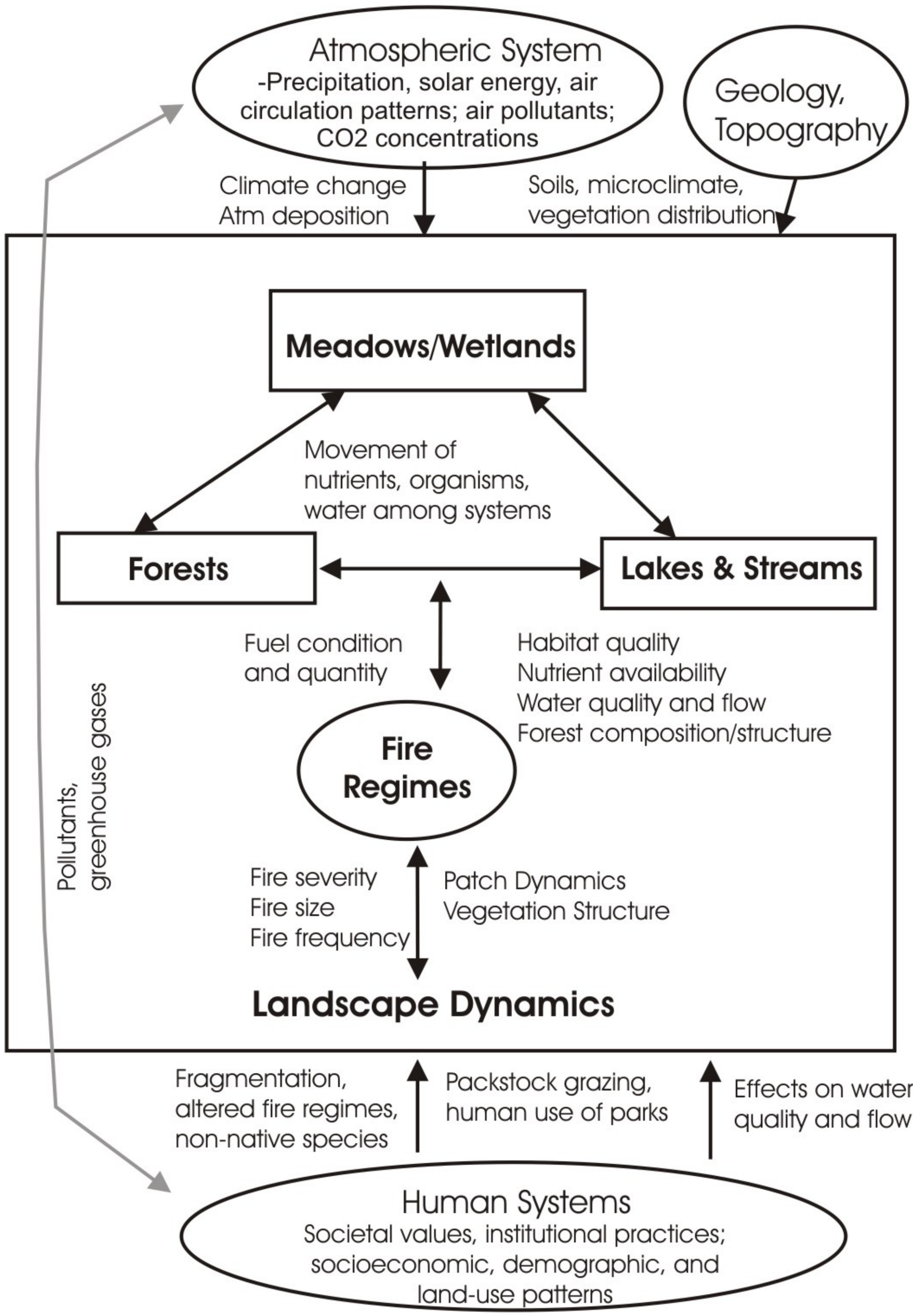


Figure I- 4. Focal Systems Model. Landscape dynamics, along with aquatic, forest and meadow/wetlands systems are the main focal systems for SIEN vital signs monitoring. Major drivers are shown in ovals and include anthropogenic influences on the Sierra Nevada; major drivers are also a focus for vital signs monitoring, especially climate, fire, invasive plants and air pollutants.

Climate affects the distribution of forest types and other plant communities of the Sierra Nevada through its influence on the soil water balance Stephenson (Stephenson 1988, Stephenson 1998). With increasing elevation, temperature decreases (causing decreasing evaporative demand) while precipitation increases. The mixed-conifer zone of the Sierra Nevada is sandwiched between low-elevation sites that are chronically droughty, and high-elevation sites that are too cold to be very productive (Urban et al. 2000). Thus, these systems are quite sensitive to climate variability (Graumlich 1993, Swetnam 1993a). The soil moisture regime interacts strongly with forest productivity (via fuel loads) and climate (via fuel moisture), and thus these systems are especially responsive to the fire regime as it interacts with forest dynamics and climate (Miller and Urban 1999c, Miller and Urban 1999a, b).

The predicted potential effects of anthropogenic climate change on the Sierra Nevada were discussed in Chapter 1. These effects will likely be highly synergistic, affecting a host of physical and biological systems in unpredictable ways (CIRMOUNT Committee 2006). Climate change will likely exacerbate other system stressors, especially altered fire regime, air pollution, and non-native invasive plants, in addition to the estimated effects it may have on the hydrologic system and plant and animal life cycles and distributions.

In addition to influencing weather and climate patterns, atmosphere dynamics interact with topography to influence air patterns, affecting the distribution and deposition of pollutants. Ozone, agricultural pesticides, particulate matter, and nitrogen compounds are a few examples of pollutants deposited through dry and wet deposition in Network parks (see Chapter 1 and Appendix C for more detail on pollutants, sources, and air flow patterns).

Fire

Fire in giant sequoia-mixed conifer forest. NPS photo.

The importance of fire as a key process and driver in the Sierra Nevada was discussed in Chapter 1. Here we emphasize the linkages between fire and climate and their roles in influencing vegetation pattern and various ecosystem processes. Climate primarily affects fire regime through its direct effect on fuel moisture. A short period of dry, hot weather can severely dry fuels, often overwhelming any effects that might be due to fuel loads or fuel bed structure. Climate also affects the geographic distribution of vegetation types and site productivity, and, thus, indirectly influences the intensity, frequency, and size of fires (Miller and Urban 1999c). Fire frequency tends to decrease with increasing elevation and soil moisture

(Figure I- 5), interacting with topographic moisture gradients and fuel availability to help shape vegetation distribution and landscape pattern. Over longer time scales, climatic fluctuations are responsible for variations in fire regimes (Clark 1988, Swetnam 1993a).

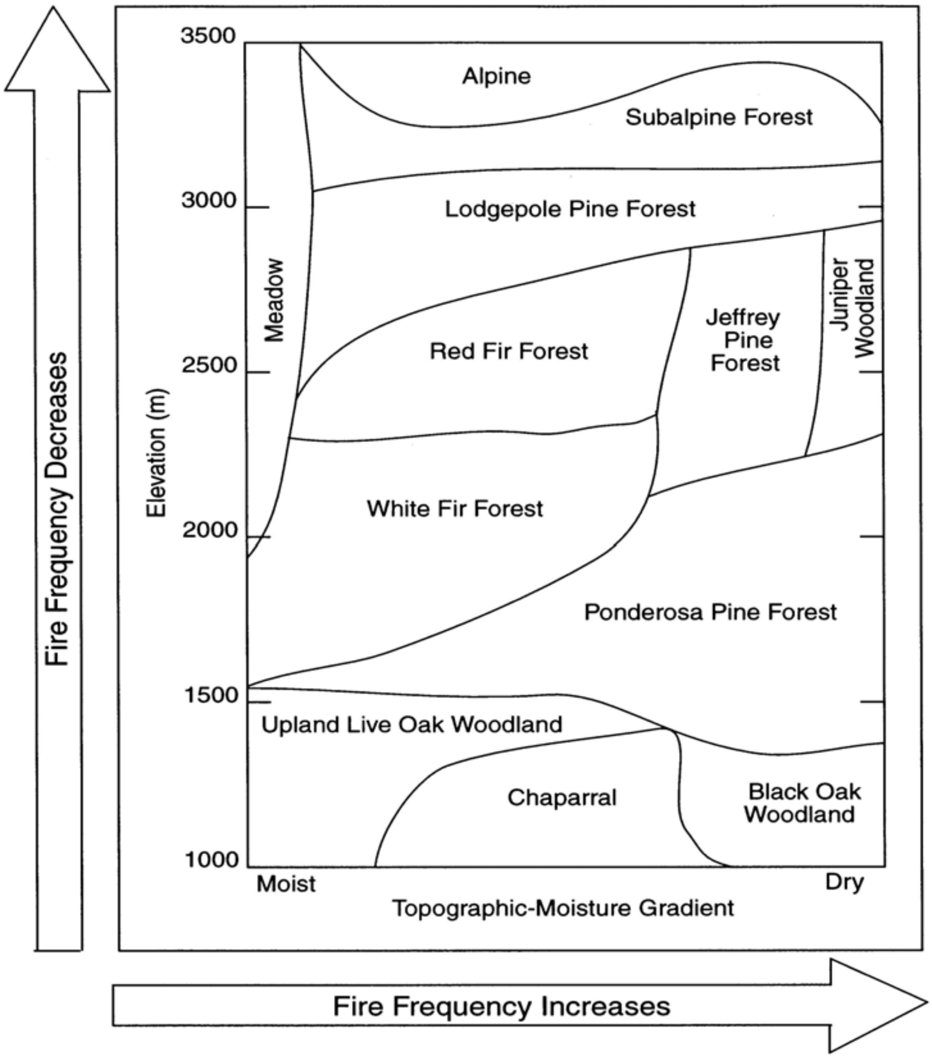


Figure I- 5: The distribution of general vegetation types (Vankat 1982) and the relation of fire frequency to elevation and topographic gradients in Sequoia National Park (Miller and Urban 1999c). This figure does not distinguish the differing effects of evaporative demand vs. water supply on vegetation distribution. See Figure I- 6 for an updated approach to modeling forest distribution based on topographic and water balance factors.

We can also consider fire a process that helps link terrestrial vegetation with aquatic, atmospheric, and soil systems. Several Sierra Nevada studies have documented increases in stream solute concentrations after fire (Chorover et al. 1994, Williams and Melack 1997a, b, Heard 2005), probably due to increased runoff, changes in biogeochemical processes, and direct deposition of ash into waterbodies. Burning and decomposition of plant material, accelerated mineralization and erosion rates, and decreased nutrient uptake by vegetation also lead to increases in solute concentrations in soil solution (Raison 1979, DeBano et al. 1998). While many elements, particularly Nitrogen, Sulfur, and Carbon are converted to volatile compounds and lost to the atmosphere (Covington and Sackett 1984, Caldwell et al. 2002), high concentrations of these elements are also left behind in ash layers and partially combusted organic material (Blank and Zamudio 1998). Fire may accelerate some losses of nutrients through combustion and leaching, but it also plays a critical role in supplying available nutrients to terrestrial and aquatic systems (St. John and Rundel 1976, Romme and Knight 1982, Hauer and Spencer 1998a). Fire releases nutrients bound in above-ground organic matter and makes them available in organic forms for plant and microbial uptake.

In summary, fire is a process that helps link terrestrial, atmospheric, and aquatic systems through its role in moving nutrients across these systems. Fire regimes in combination with climate and topography, shape vegetation structure and pattern on the landscape, affect water quality and quantity, and indirectly affect wildlife habitat.

<u>Geology and Topography</u>

The Sierra Nevada physical landscape was shaped by glaciation, volcanism, erosion, and deposition. The varied topography provides habitat diversity for plant and animal communities. As described in Chapter 1, the elevation gradient influences local weather and climate patterns, with a general trend of temperatures decreasing and precipitation increasing with elevation. Because the mountains create a rain shadow, significantly less moisture falls throughout the season east of the Sierra Nevada crest. Topography also influences microclimatic conditions through variations in aspect, e.g., north aspects have lower temperatures and thus evaporative potential. So they tend to be more moist and cooler than south-facing slopes. Soils vary in type and depth, influencing plant community distribution through their nutrient availability and water-holding capacity. See Figure I- 6 for the influence of aspect and soil depth on forest distribution.

Glacially-carved Tehipite Valley in Kings Canyon National Park. NPS photo.

Human Systems

California has 34 million people, by far the most populous state in the Union. The San Joaquin portion of California's Central Valley, located to the west of the Sierra Nevada Network parks, is a region that holds a population of 3.4 million or ten percent of California's population, according to the 2000 census (United States Census Bureau 2003). By the year 2020, the San Joaquin portion of the Central Valley will have over six million people according to population projections by the California Department of Finance (Report 93 P-1). The Sierra Nevada parks are also within four to five hours of driving distance from the largest cities of California.

View from Sequoia National Park toward the Central Valley on a good air day and a bad air day. NPS photo.

Current regional levels of population, agribusiness, and other industry combine with topography and weather patterns to result in some of the worst air quality in the country (see Chapter 1 and Appendix C). In addition, California agriculture uses a large percentage of water resources in the state. If state and regional population numbers double between 2000 and 2020, this will inevitably change land use patterns and have a dramatic influence on quantity of arable land, air quality, water quality and availability, energy resources, and biodiversity. These changes will have direct effects on park resources in the form of atmospheric transport and deposition of pollutants and nutrients, light in night skies, noise from overflights, increased development and urbanization, increased park visitation, and more greenhouse gas emissions accelerating global climate change.

Societal values and social systems govern many of the interactions of the human system with the Sierra Nevada eco-region and parks. For example, the popular press increasingly cites evidence of a weakening of the historically strong link between Americans and the natural world. Writers cite many different forms of evidence for this trend, including stagnant visitation statistics for national parks and continued declines in the number of Americans who sport hunt (Tweed 2006). Sustaining support for wildlands preservation in a democracy, it has long been believed, depends upon substantial numbers of citizens using and enjoying their public lands. In addition to the effects of public policy and federal laws that modify human interactions with the landscape, personal values also affect the long-term compatibility of land use and wildlands resources preservation. Future changes in socioeconomic, demographic, and land-use patterns in combination with changes in social systems and values will present many challenges for Sierra Nevada Network parks.

Focal Systems – An Introduction

<u>Meadows/Wetlands</u>

Meadows concentrate resources, provide critical habitat for both resident and transient animals, and have been identified as key ecosystem elements in the Sierra Nevada Network parks. Meadows are diverse and complex ecosystems that vary widely in character and composition, although occupying only a small fraction of the land surface of the Sierra Nevada (Benedict and Major 1982, Ratliff 1982). Meadows form in catchments where soils are saturated or flooded for at least a part of the year. Sierra Nevada meadows range in size from small patches to large expanses, such as Tuolumne Meadow in Yosemite National Park. Most Sierra Nevada meadows occur above snowline, where snowmelt provides moisture during the summer growing season. In addition to surface flow, moisture enters meadows from streams and from sub-surface flows that are forced to the surface by local geomorphology. Meadows can be characterized as wet, moist or dry, reflecting the relative availability of moisture during the summer growing season. Sierra Nevada meadow vegetation is dominated by perennial graminoids, which reflect the relatively short growing season of the middle and high elevations.

Sampling invertebrates in Tuolumne Meadow, Yosemite National Park. Photo by Jutta Schmidt-Gengenbach.

As wetlands, wet meadows provide important ecological and cultural functions. Some of the functions described by Mitsch and Gosselink (Mitsch and Gosselink 1993) and Williams (1990) that might apply of the Sierra Network meadows include: 1) influencing regional water-flow regimes including flood mitigation by intercepting and slowing the release of water to streams; 2) improving water quality by removing nutrients and toxic materials; 3) sediment trapping; 4) sources for some of the highest productivity in the world; 5) important habitat for wildlife; and 6) aesthetic values to the people that visit them. Peat-accumulating wetlands in their natural condition remove and store carbon. If altered, such as by drainage, the process would reverse contributing to atmospheric carbon dioxide through oxidation (Gorham 1991). Wetlands play an important role in the nitrogen and sulfur cycles.

A more complete description of meadow and wetland systems can be found associated with the meadow conceptual model (Figure I- 255).

Aquatic Systems: Lakes and Streams

As summarized in Chapter 1, the Sierra Nevada parks span seven major watersheds and contain a diversity of water resources, including over 4,500 lakes and ponds, thousands of kilometers of rivers and streams, seeps, wet meadows, waterfalls, hot springs, mineral springs and karst springs. Water is a vital resource in the Sierra Nevada, both ecologically in the parks, and economically in the broader region. We are interested in monitoring water resources both for their sensitivity to important drivers and stressors (climate, fire, air pollution, invasive species) and their link to other critical biotic and physical resources.

Alpine lakes in Evolution Basin, Kings Canyon National Park. NPS photo.

Through the hydrologic cycle, water is linked to the atmospheric and terrestrial systems. In the Sierra Nevada, the snowpack that accumulates in the winter serves as a reservoir for water that is released gradually in the spring to the aquatic system of groundwater, wetlands, streams and lakes to be available during the dry summer growing season. Both the quantity and quality of water help to determine the condition of terrestrial as well as aquatic biological systems.

High elevation lakes and streams in the Sierra Nevada are oligotrophic, have a low buffering capacity, and are sensitive to change from atmospheric deposition of nutrients, toxic substances, and acids (Goldman et al. 1993, Leydecker et al. 1999, Davidson and Shaffer 2002, Sickman et al. 2003). Change detected in high-elevation lakes can be an early warning indication of change that may eventually occur at other elevations and ecosystem types. To complement the early warning indicators at high elevation aquatic systems, monitoring of water quantity and quality in mid- to low-elevation streams and rivers can indicate cumulative effects of changing terrestrial and aquatic ecosystem processes and disturbances that take place throughout a watershed.

Water availability is a major driver in the distribution of plant communities. Thus, tracking water quantity changes over time may provide an early warning of later changes in soil moisture that could cause gradual shifts in plant population dynamics and community distributions on the landscape. See Figures I-21 through I-24 and associated text for more detail on Sierra Nevada aquatic systems.

Forests

Sierra Nevada montane and subalpine coniferous forests comprise one of the largest and most economically important vegetation regions in California (Rundel et al. 1988). They are very complex in composition, structure, and function (Franklin and Fites-Kaufmann 1996). We are interested in monitoring forest dynamics, and primarily—birth, growth and death rates of trees, because they are sensitive to changes in the two major drivers in the Sierra Nevada: climate and fire regimes. These two drivers are subject to substantial alteration by human impacts, and in these altered states can act as stressors on forest systems.

Giant sequoia-mixed conifer forest. NPS photo.

Sierra Nevada forest distributions are linked to moisture availability as determined by topography, soil depth, and evaporative demand (Figure I- 6). Moisture availability affects growth, recruitment and death rates of trees as well as frequency and intensity of fire. Recent research results suggest that forest dynamics may already be showing effects of climatic changes. Forest turnover rates (defined as the average of tree mortality and recruitment rates) have been increasing in tropical Amazonia (Phillips et al. 2004) and in the Sierra Nevada (Stephenson and van Mantgem 2005). In the Sierra Nevada, a possible cause for this more rapid forest turnover rate is that summers have been getting warmer and drier. Snowpack has been decreasing over most of the West in recent decades (Mote et al. 2005) and spring streamflow has been occurring earlier (Stewart et al. 2004).

Sierra Nevada montane forests are highly dependent on fire (See Chapter 1 and Appendix I for more detail). A variety of studies suggest that past Sierran mixed conifer forests had lower tree density, and very different demographic distribution of age classes—with lower fuel loads and greater landscape diversity of forest patches than current forests (Vankat and Major 1978, Parsons and DeBenedetti 1979, Bonnicksen and Stone 1982, Vale 1987, Ansley and Battles 1998, Roy and Vankat 1999, Stephenson 1999). While many of the changes observed in forest structure and function are thought to be primarily due to fire exclusion, they may also be related to warmer, moister conditions of the 20th century (Graumlich 1993, Scuderi 1993, Keeley and Stephenson 2000).

Monitoring of forest dynamics will need to be linked to monitoring of fire regime, fire effects, and climate to enable effective interpretation of trends in tree population dynamics and large-scale forest landscape changes in pattern and structure. See Figures I-19 and I-20 and associated text for more detailed information about forest dynamics.

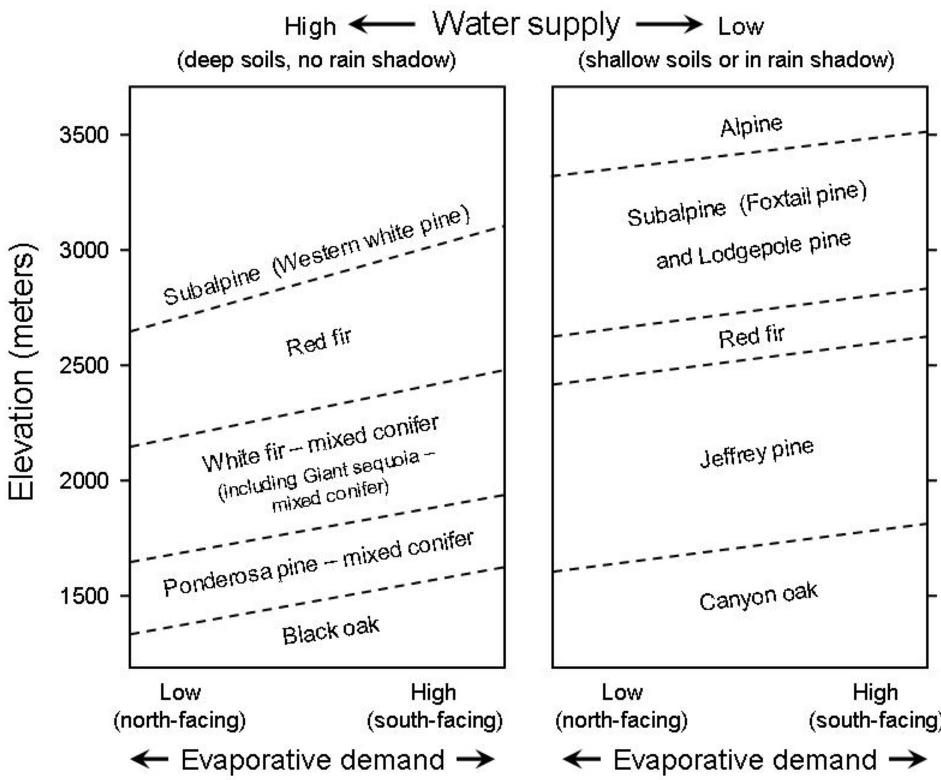


Figure I- 6. The approximate distribution of forest types in the southern Sierra Nevada relative to elevation, evaporative demand, and water supply. Only upland forest types (away from open water and meadow edges) are shown. Forest types intergrade extensively, so that boundaries between types are not sharply defined. In particular, intergradation between foxtail pines and lodgepole pines is so extensive that no boundary between the two types is shown, although foxtail pines dominate at the highest elevations, lodgepole pines at lower elevations. Because deep soils able to retain abundant water disappear at high elevations, no upper treeline is indicated in the high water supply diagram. (Modified from Stephenson 1988.)

System Models and Associated Detailed Models

Introduction

This section presents draft models of the main focal systems selected for vital signs monitoring in the Sierra Nevada Network. Associated with these focal systems models are more detailed models that describe ecosystem processes (such as hydrologic systems, fire regimes, nitrogen deposition, and invasion of non-native plants), effects of drivers on plant and animal community dynamics and population dynamics of focal species, and interactions among biotic and physical components in specific systems such as lakes.

We present models that include most of the network's vital signs that are selected for network protocol development, or that are already being monitored by the parks. We summarize linkages among the vital signs and the models in Table I- 2, and by cross-referencing vital signs in some of the models to the numbers in Table I- 2. As stated in the introduction to this appendix, more work will need to be done for the final Phase III Report to standardize models (including symbols used among models), structure accompanying model text similarly among models, and focus on making more explicit links to our vital signs and protocols. We may consider developing models as part of some or all of the vital signs monitoring protocols, as models have the potential to inform sample design and interpretation of monitoring results.

Table I- 2. High-priority vital signs of the Sierra Nevada Network and conceptual models. Bolded vital signs are the ones that the network has selected for protocol development. Others are being monitored in parks. Numbers are used to cross-reference vital signs shown in models.

	Top Vital Sign	Conceptual Models
1	Air quality-ozone	Stressor, atmospheric, landscape
2	Air quality-atmospheric deposition	Stressor, atmospheric, nitrogen deposition, landscape
3	Air quality-particulate matter	Atmospheric
4	Air quality-contaminants	Atmospheric, lakes, amphibian
5	Air quality-visibility	Atmospheric
6	***Weather and climate***	Focal systems, Atmospheric, driver in many models
7	***Snowpack***	Landscape, aquatic system
8	Geomorphology- stream channel morphology	Monitored in YOSE by park staff, no model
9	Subsurface geologic processes-cave/karst physical processes	Monitored in SEKI by park staff, model in rough draft form and not included.
10	***Hydrology-surface water dynamics***	Aquatic system, Hydrology
11	***Hydrology-wetland water dynamics***	Aquatic system, Meadow
12	***Water quality-water chemistry***	Aquatic system, Aquatic biota
13	***Invasive species- non-native plants***	Community invasibility models, Forest dynamics, Aquatic system
14	***Meadow plant communities***	Meadow
15	***Meadow invertebrates***	Meadow, Invertebrates
16	***Forest stand population dynamics***	Forest dynamics
17	***Amphibians***	Aquatic system, mountain yellow-legged frog
18	***Birds***	Bird populations
19	***Fire regimes***	Focal system, forest dynamics, landscape, fire regimes
20	Fire effects on plant communities	Fire regimes, landscape dynamics
21	***Landscape mosaics***	Landscape dynamics
22	Phenology	Landscape dynamics

Atmospheric System

Our model and text for this section are adapted from Miller et al. (2006), Draft Conceptual Ecological Models for the Mojave Network Inventory and Monitoring Program.

The atmospheric system drives weather, and the long-term characteristics of weather are described as climate. The atmospheric system conducts most mass and energy, including pollution, to and from the Sierra Nevada Network. The atmosphere receives solar radiation, which is mediated by reflective aerosols and absorbent trace gases before reaching Earth's surface (Figure I- 7). It also receives water vapor from evaporation at the Earth's surface and transpiration from plants. In this zone near the Earth's surface, heat exchange mediates the vertical temperature gradient in the atmosphere (Bradley 1985). Although the atmosphere has low heat capacity, it couples with water bodies of much higher heat capacity with the result that energy in the atmosphere is primarily driven by ocean circulation patterns. Interactions between atmosphere and land include evaporation and transpiration, reflected radiation, precipitation, wind, and heat exchange.

Strong climatic gradients develop with changing elevation in the Sierra Nevada, from west to east. Low to mid-elevations have a Mediterranean climate, which is characterized by hot, dry summers and cool, wet winters. Higher elevations are dominated by a Microthermal (or Boreal) climate, which is characterized by having average temperatures of the coldest month below -3°C. As a result, a steep temperature gradient parallels the elevation and climatic gradient; on average, each 100 m gain in elevation results in a 0.6 C° drop in air temperature. This lapse rate varies locally according to air speed, relative humidity, slope aspect, insolation, and vegetation cover (Stephenson 1988), but the general pattern holds true as one climbs from the hot lowlands to the alpine crest.

As temperature decreases with increasing elevation, so does the moisture-holding capacity of air. Winter precipitation is strongly orographic (e.g. related to increase in elevation due to mountains), increasing along the west slope of the Sierra Nevada from approximately 50 cm at lower elevation sites to 200 cm at higher elevations. Above 2100 m on the western slope, about 50% of precipitation falls as snow (Stephenson 1988), creating a significant snowpack in the montane and subalpine elevations. By the time winter storms reach the alpine, much of the moisture has been lost from the clouds and the amount of snow accumulating on the ground begins to decline with increasing elevation. East of the crest, the mountains create a rain shadow with significantly less moisture falling throughout the season. Precipitation also increases with latitude, due to the pacific jet stream position and subtropical high pressure cells. Across elevations and latitudes, nearly 70% of precipitation falls from December through March and only about 4% from June through September (Stephenson 1988).

Topography directly influences the amount and timing of precipitation as well as variability in temperature across large and localized spatial scales. As is evident in Figure I-6, elevation, aspect and soil depth interact with climate to influence evaporative demand, and distribution of Sierra Nevada forest types.

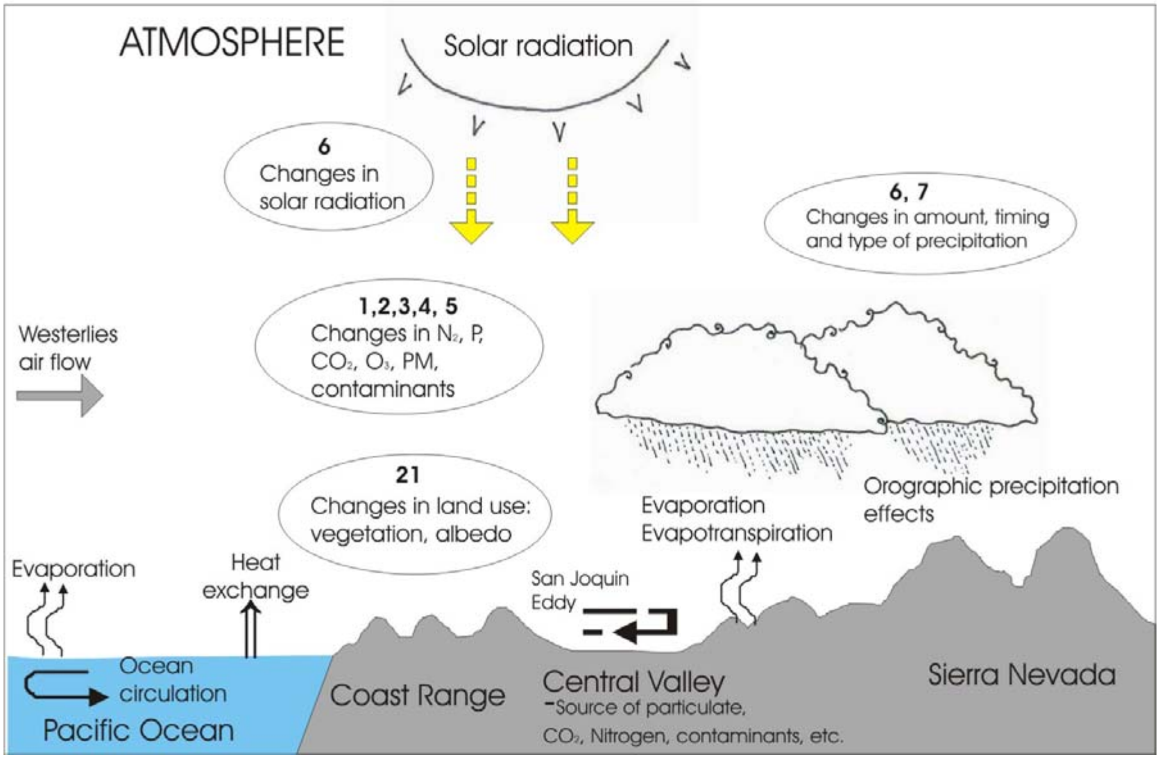


Figure I- 7. Atmospheric system model for Sierra Nevada. Principal components of the atmospheric system, some drivers (in ovals), and key landscape features are shown. Bolded numbers link to vital signs in Table I-2. Abbreviations: N_2=nitrogen, P=phosphorous, CO_2=carbon dioxide, PM=particulate matter.

Climatic forces are a major driver of Sierra Nevada ecosystems. Current patterns of vegetation, water dynamics, and animal distribution in the Sierra are determined largely by cumulative effects of past and present climates. Anthropogenic climate change is the driver that is predicted to have the most pronounced effects on Sierra Nevada ecosystems. Some of the expected or already occurring changes include:

- Earlier snowmelt runoff, reduced summer base flows and soil moisture (Dettinger et al. 2004, Dettinger 2005a)
- Lower snowpack volume at mid-elevations (Knowles and Cayan 2001)
- Increased winter and spring flooding (Dettinger et al. 2004)
- Increased turnover rates in forests (Stephenson and van Mantgem 2005)
- Upward shifts in species or habitats, and losses of species that cannot adjust; potential shrinkage of some habitats (alpine, wetlands)
- Altered fire regimes – larger, more severe fires (Torn and Fried 1992, Miller and Urban 1999c)

The Sierra Nevada Network selected weather and climate as a vital sign because 1) changes in regional climate patterns will cause change in the ecosystem and 2) climate data will be used to explain patterns observed in other indicators.

Atmospheric dynamics combine with emissions of air pollutants to influence air quality. The San Joaquin Valley, west of the Sierra Nevada parks, is a trap for air pollutants originating in the valley as well as pollutants from cities along the central California coast that are carried in on prevailing winds. Southward-flowing air currents enter California at the San Francisco Bay and move through the valley until they reach the mountains at the southern end of the basin, causing an eddy to form in the vicinity of Visalia and Fresno, just west of the southern Sierra Nevada (Figure I- 8) (Lin and Jao 1995). Thermal inversions frequently trap air over the valley at night during the summertime. Airborne pollutants are then transported into the mountains when this air rises during the day. As a result, Sequoia and Kings Canyon have some of the worst air quality found in any NPS unit in the country (Cahill et al. 1996). Yosemite and Devils Postpile are also impacted, but to a lesser degree.

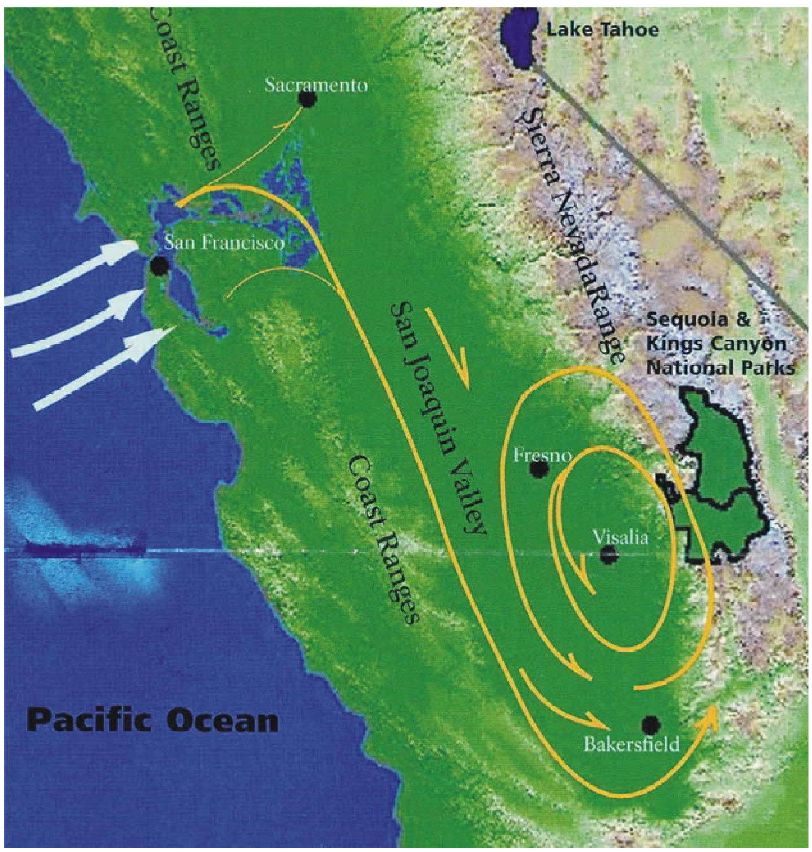


Figure I- 8. Air flow patterns in San Joaquin Valley. The air currents carry pollutants from the San Francisco Bay area and the Central Valley and circulate them against the Sierra Nevada.

The Sierra parks are subjected to pesticides, nitrogen-based and sulfur-based pollutants, and elevated levels of ozone:

Nitrogen: Inputs of fixed nitrogen into ecosystems of the United States have doubled since 1961 due mainly to agricultural application of nitrogen fertilizers, combustion of fossil fuels, and industry (Howarth et al. 2002). In the Sierra Nevada nitrogen deposition has become a major concern (Fenn et al. 2003). Ammonium nitrate (NH_4NO_3) is a major component of the fine particulate matter deposited in Sequoia and Kings Canyon National Parks (Esperanza & van Mantgem in Appendix C of this document), and is likely active in altering the lichen communities of the Sierra parks ((McCune et al. 2006). In Sequoia National Park, ammonia and ammonium are the dominant N pollutants in summer, indicating strong influence of agricultural emissions (Bytnerowicz et al. 2002).

Ozone: Ozone is a photochemical pollutant formed when nitrogen oxides (NO_x) and hydrocarbons react with oxygen and sunlight. Tropospheric ozone (O_3) pollution is widespread in California, occurring in both urban and rural areas, and causing injury to both wild and crop plants (Miller 1973, Duriscoe and Stolte 1992, Peterson and Arbaugh 1992, Stolte et al. 1992, Miller 1996), as well as causing human health problems because it damages lung tissue, reduces lung function and sensitizes the lungs to other irritants.

Acid Deposition: Acid deposition is the generic term to include wet and dry deposition of acidic forms of mainly nitrogen and sulfur compounds. Acidic derivatives of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are the principle acidifying agents. In the Sierra Nevada, air monitoring suggests that sulfuric acid is likely to be less of a problem than nitric acid. Sierra lakes have shown sensitivity to even low levels of acid deposition due to thin topsoils, granitic subsurface layers, sparse vegetation, steep slopes, and a dry climate. Precipitation in the Sierra Nevada comes during late summer rains and spring snowmelts, delivering acidic pulses of water to lakes and creeks (Stohlgren and Parsons 1987, Melack and Sickman 1995, Melack et al. 1998a).

Pesticides: Sequoia, Kings Canyon and Yosemite are downwind of one of the most productive agricultural areas in the world, the San Joaquin Valley. Every year, tons of pesticides are applied to crops – 2 billion pounds of active ingredients were applied in California between 1991 and 2000 (Pesticide Action Network in Esperanza & van Mantgem, Appendix C of this document). Pesticides volatilize or become suspended in the atmosphere as particulates, then drift into the parks on prevailing winds.

Sulfur-based pollutants: Fossil fuel combustion, vehicle exhaust, paper manufacturing, and industries produce SO_2. Although levels of SO_2 toxic to lichens are found in Los Angeles and other urban areas, SO_2 occurs in relatively low concentrations in more remote areas in California (Jovan and McCune 2005).

The severity of air pollution may worsen with warmer climate conditions, as warm temperatures create the perfect conditions for the production of "smog," or ground-level ozone. The monitoring of climate and the various indicators associated with poor air quality in the Sierra Nevada will be important in understanding current changes in physical processes in aquatic and terrestrial systems, nutrient dynamics, and plant and animal communities, as well as in modeling future changes in these systems.

Nitrogen Deposition

Nitrogen (N) is a limiting nutrient for many terrestrial and aquatic organisms (Vitousek and Howarth 1991). The biogeochemistry of nitrogen is complex with significant control of its cycling relegated to biotic processes (Delwiche 1970). We include a model illustrating possible linkages among nitrogen deposition, N cycling, carbon allocation, invasive plant species, fire regime, and community composition (Figure I- 9) because of documented increased deposition of nitrogen to Sierra Nevada ecosystems (Fenn et al. 2003a). The SIEN parks have limited monitoring of nitrogen through wet and dry deposition monitoring at a few air quality sites (see Appendix C), and through the vital signs monitoring program we include nitrate, dissolved organic nitrogen, total dissolved nitrogen, and particulate nitrogen as components of planned water chemistry monitoring in Sierra Nevada lakes.

There has been a slow, steady increase in atmospheric nitrogen deposition in park watersheds (Lynch et al. 1995). There are resultant biological effects of nitrogen deposition on aquatic and terrestrial ecosystems, and this enrichment can have considerable effects on sensitive organisms or communities (e.g. lichens and phytoplankton)—even at very low levels of atmospheric deposition (Fenn et al. 2003).

In spite of increasing nitrogen deposition, however, there has been a decrease in dissolved nitrogen leaving watersheds (Melack et al. 1998b). These changes parallel an observed shift in the phytoplankton community of Emerald Lake in Sequoia—from a lake dominated by phosphorus limitation to one dominated by nitrogen limitation. Mixed-conifer watersheds in Sequoia's Giant Forest also have shown net retention of nitrogen, with stream concentrations often below detection limits (Williams and Melack 1997a). Elevated nitrate concentrations have been observed in lake and stream water samples from the upper Merced River watershed of Yosemite (D. Clow, pers. comm.). With continued urbanization of California's Central Valley, with increasing livestock operations, and with the possibility of transpacific N transport from Asia, it is probable that N deposition and its ecosystem effects in the High Sierra will increase in the next several decades (Fenn et al. 2003).

The consequences of increased nitrogen deposition and retention on terrestrial plant communities in the Sierra Nevada are unknown, but greater foliar biomass production, resulting in enhanced litter accumulation on the forest floor (fuel) and in aboveground biomass (stand densification), may increase the risk of severe fire damage (Fenn et al. 2003). Nitrogen pollutants are likely to be important in causing changes in lichen communities (e.g. shifts to nitrophilous species, changes in abundance)(Nash and Sigal 1999). Increased levels of soil nitrogen caused by atmospheric nitrogen deposition can increase the dominance of invasive alien plants and decrease diversity of native plant communities (Vitousek and Howarth 1991, Vitousek et al. 1997). Enhanced growth of invasive species from increased nitrogen has been observed in coastal sage scrub of Southern California, and is implicated in exacerbating invasion of Mediterranean nonnative grasses (Allen et al. 1988). Changes in the alpine plant community of the Rocky Mountains from nitrogen deposition have been observed (Bowman 2000).

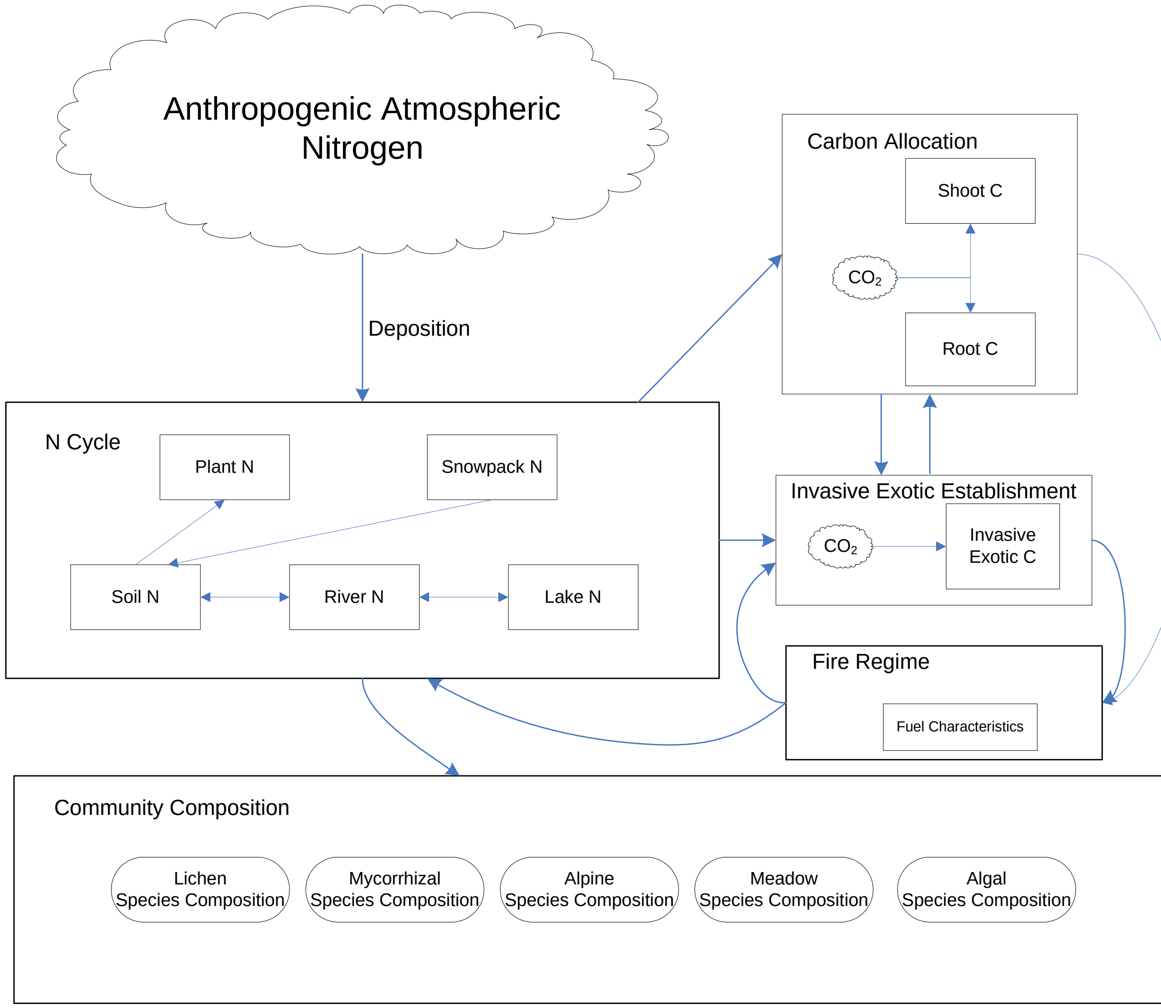


Figure I- 9. Relationship of nitrogen deposition to other ecosystem processes and components.

Landscape Dynamics

There are a variety of major factors that are threatening the integrity of Sierra Nevada ecosystems. Regional science has identified habitat fragmentation, invasive species, altered fire regimes, pollution, and anthropogenically driven climate change as the five primary threats to Sierran systems (SNEP 1996). With a rapidly expanding human population and a steeply rising projection in the state's population size, these threats are likely to only increase in scope and severity. In particular, the Sierra Nevada foothills are projected to be heavily impacted by future development. Climate change is also predicted to play an increasingly important and serious role in California, posing a significant threat to the existence and persistence of native ecosystems and species (CEC 2003; Hayhoe et al. 2004). Decades of fire suppression and predicted climate shifts are likely to bring dramatically altered fire dynamics to the Sierra Nevada.

We have selected landscape dynamics as a high priority monitoring protocol to develop because many landscape elements and processes are sensitive to the threats identified above (see Figure I- 3 and associated discussion for more detail on these stressors). Another reason we are interested in monitoring landscape dynamics is that remote-sensing technology provides a cost-effective means of detecting and assessing change in our large Wilderness parks where on-the-ground monitoring will not be feasible for all vital signs.

In this section, we highlight the high-priority vital signs we have identified for monitoring at the landscape-scale through the use of remote-sensing, illustrate linkages among drivers (including primarily anthropogenic threats), ecosystem effects, and key indicators or vital signs associated with these drivers and effects. We also discuss landscape change that has already been observed in the Sierra Nevada through the use of repeat photography. We include definitions of landscape terminology in the text box below.

Landscape Definitions

Ecosystem: a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (Convention on Biological Diversity 2005)

Landscape: a mosaic where a cluster of local ecosystems is repeated in similar form over a kilometers-wide area (Forman 1997)

Landscape element: each of the relatively homogeneous units, or spatial elements recognized at the scale of a landscape mosaic. This refers to each patch, corridor, and area of matrix in the landscape (Forman 1997)

Mosaic: a pattern of patches, corridors, and matrices, each composed of small similar aggregated objects (Forman 1997)

Landscape mosaic: a geographic group of site-level ecosystems (Bailey 1998)

Patch: a relatively homogeneous nonlinear area that differs from its surroundings (Forman 1997)

In priority order, these are the vital signs we hope to include in the landscape dynamics monitoring protocol. Limitations of funds for image acquisition or remote-sensing data interpretation may restrict us to monitoring fewer vital signs than we list below:

1) Landscape mosaics:
    - landscape pattern (land cover, land use);
    - landscape composition (distribution and abundance of landscape units)
    - vegetation condition

2) Fire regimes:
    - landscape composition (distribution and abundance of landscape units, such as spatial and temporal extent of fires, fire type)
    - vegetation condition (fire severity)

3) Snowpack:
    - timing of snow cover initiation, melt off, and peak snow depth
    - extent and duration of snow cover

4) **Vegetation phenology*:
    - timing and duration of leafout and growing season

5) Specific indicators associated with forest dynamics, lakes and meadows protocols (not in priority order):
    - forest patch size dynamics and forest condition
    - ice-out of alpine and other high-elevation lakes
    - extent and spatial arrangement of meadows/wetlands
    - invasion and spread of non-native plants

6) *Glaciers* (not on our selected list of vital signs at this time, but may be considered as part of the landscape protocol if economically and logistically feasible)
    - spatial extent and distribution

*Phenology is on our top-35 list of selected vital signs that we present in chapter 3 of our monitoring plan. It was not selected for immediate protocol development as national guidance is expected in the next year that will outline recommended approaches for phenological monitoring. For now, we include it as part of our landscape-level protocol development.

We use a driver-stressor model to highlight linkages among the drivers (which include primarily anthropogenic stressors of highest concern and interest), the ecosystem effects they are known to produce in the Sierra Nevada and elsewhere, and the indicators that we have identified as being responsive to these drivers (Figure I- 10). More mechanistic or control models may be needed as the protocol is developed, to explore more specific interactions among drivers and landscape elements. Spatially explicit models, and models that consider change at different time scales will be important next steps to assist with protocol development decisions.

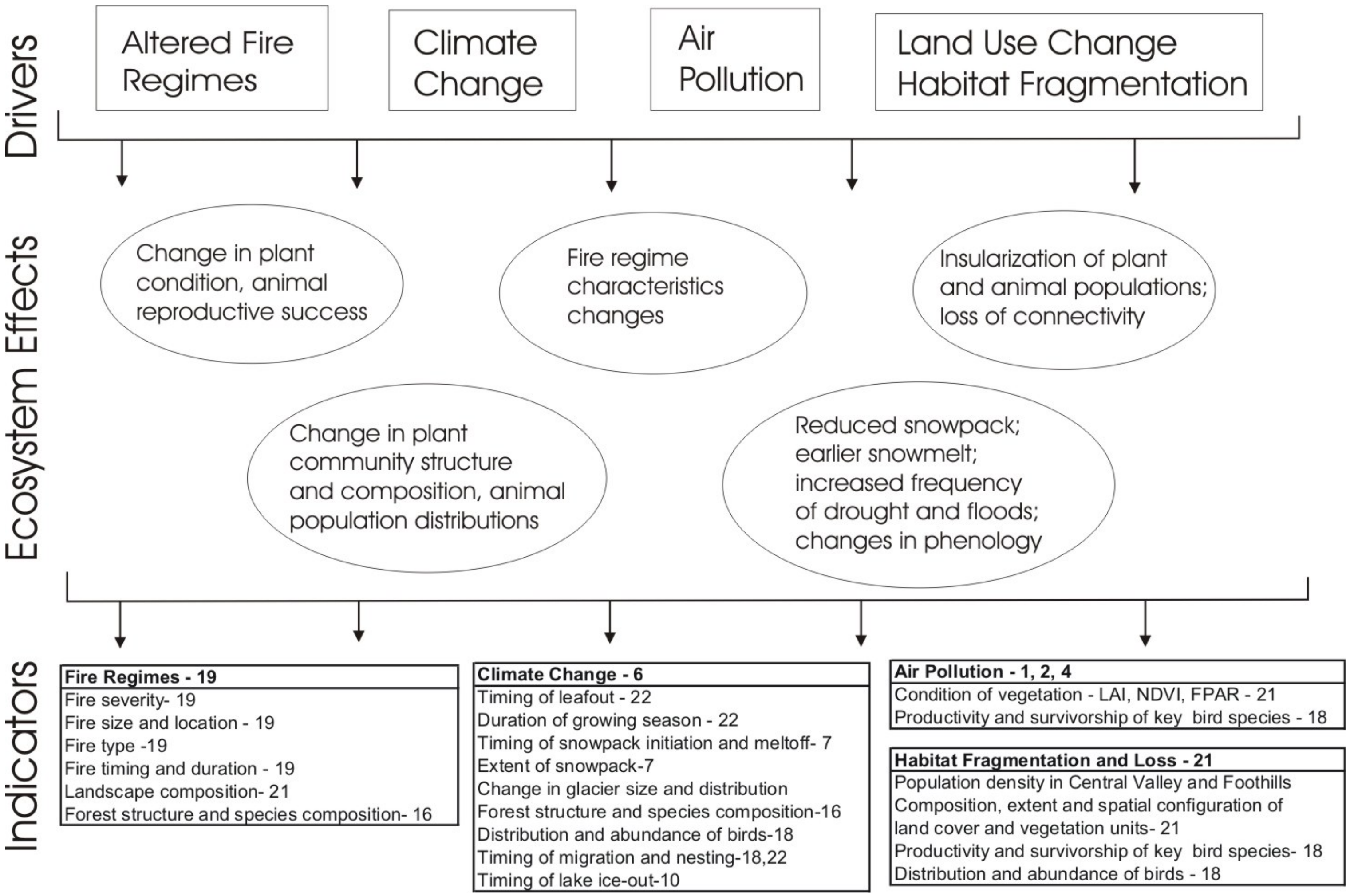


Figure I- 10. Sierra Nevada landscapes dynamics conceptual model. Emphasized in this diagram are major drivers of landscape change, ecosystem effects, and indicators of change most closely related to the major drivers. Numbers next to indicators or drivers in the lower boxes correspond to vital signs numbers in Table I- 2.

Indicators of Habitat Fragmentation and Loss

Large portions of the larger Sierra Nevada parks (Kings Canyon, Sequoia and Yosemite) are buffered to some extent from the effects of habitat fragmentation and land use change that occur in the Central Valley of California to the west of the parks, in the Sierra Nevada foothills, and on Sierra Nevada national forest lands. Nonetheless, edges of the parks that border these lands as well as areas that extend into the parks are affected by such things as non-native species invasions, indirect effects of urbanization and deforestation (such as reduced wildlife habitat outside parks and loss of connections among habitats), deterioration of air quality, and deterioration of natural soundscapes and dark night skies.

Land Cover Change

Land cover and land use change may be one of the most important components of a long-term monitoring program. Quantifying the occurrence of land cover/use classes within a particular area over multiple time periods allows for the detection of change in the relative occurrence of natural, agricultural, and urban cover types, and provides an index for the potential direct (e.g. decreased functional ecosystem size through loss of habitat area, elimination of unique habitats) and indirect (e.g. edge effects, altered ecological flows across landscape, increased human disturbance) ecological impacts of urbanization on park resources (Hansen and Gryskiewicz 2003). Land cover/use characterization captures changes related to urbanization and logging, which are equally relevant to all park landscapes and ecosystems, but particularly relevant to areas along the edges of our parks that border private and other land management agency lands (USFS, BLM).

Population Density

Excerpted from Hansen and Gryskiewicz (2003):

"…Population density is a demographic measure which can be especially useful for monitoring patterns of urbanization, because the influx of people into formerly rural areas indicates a transition to a landscape dominated by urban activities and land cover types. Increases in population density around parks indicate that negative ecological impacts of urbanization may potentially influence park resources, with greater rates of increase indicating greater potential impacts. These land use changes may be linked to park ecosystem functioning through mechanisms which are related to higher levels of human activity within the landscape, including edge effects stemming from the intensification of the human-wildland interface, alteration of hydrologic flows, and human recreation and disturbance. Population density is an index of urbanization that is applicable to all landscapes, and is measured consistently across space and time…" so can be equally relevant to all SIEN parks as a monitoring tool.

Bird Populations

See bird model that follows (Figure I- 15) for information about factors affecting bird populations and why they are sensitive indicators of habitat fragmentation, climate change, and contaminants.

Indicators of Air Pollution Effects on Ecosystem Condition

One of the most damaging air pollutants is ozone. Research suggests chronic ozone pollution can lead to shifts in forest structure and composition (Miller 1973). If current ozone concentrations remain relatively constant or increase, they may affect the genetic composition of pine and sequoia seedling populations, and contribute to increased susceptibility to fatal insect attacks and death rates, and decreased recruitment (Miller 1973, Ferrell 1996, Miller 1996). The effects of chronic ozone pollution on other species are not yet known. Certain remote-sensing metrics (such as Leaf Area Index, Normalized Difference Vegetation Index) may be applicable to detection of tree dieback from various causes. Currently, the US Forest Service coordinates flights over the parks each year to hand-map areas of tree dieback. The data from these flights could be useful in comparing to and checking interpretation of remotely-sensed imagery of vegetation condition.

Indicators of Climate Change

Snowpack

Snow is the dominant environmental factor in mountainous regions for more than half of the year (Mote et al. 2005). Sierra Nevada snowpack acts as a temporary reservoir, storing water until the spring snowmelt. In the alpine and subalpine, snowpack protects vegetation from the abrasive and dehydrating effects of wind, and wind driven snow, effectively limiting the height of most woody vegetation to that of the snowpack. Recent modeling work predicts that the average temperature in California will increase 2.1°C by 2090, which will result in a loss of 43% of the April snowpack in the southern Sierra Nevada (measured as snow water equivalent) (Knowles and Cayan 2001, 2002, Mote et al. 2005). Monitoring of snowpack at the landscape scale provides information directly related to changing climate and relevant to the water supply of the region, which has both high ecological and economic value.

Glaciers

The Sierra Nevada contains approximately 497 alpine glaciers and perennial ice features (Raub et al. 1980). These features provide an opportunity to determine regional responses to warming global temperatures over the past century. During the summer of 2003 and 2004, over 52 repeat images of historic photos were collected from ten glaciers located throughout the Sierra Nevada, providing evidence of glacial shrinking in the past 100+ years (Figure I- 11).

Timing of Lake Ice-out

This information would complement other planned lake monitoring (water chemistry, surface water dynamics and could be sensitive to warming climate condition).

Birds

See bird model and discussion (Figure I- 15).

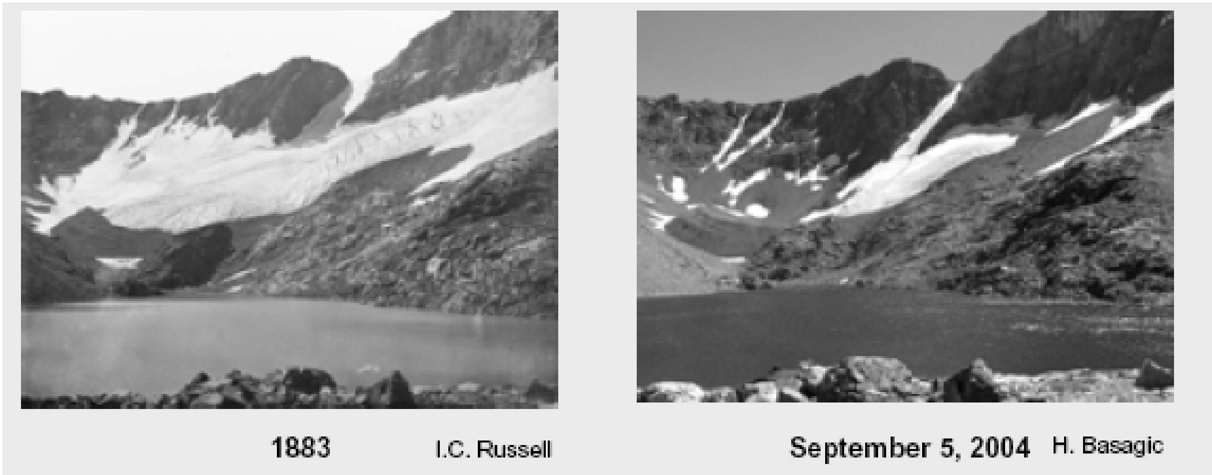


Figure I- 11. Repeat photos of Dana Glacier, Yosemite National Park.

Forest structure and composition
Remote sensing offers the possibility of detecting broad-scale changes either missed or poorly represented by small, dispersed forest plots, thus it offers a monitoring approach that is complementary to plot-based monitoring. These kinds of forest changes could be detected using remote-sensing technology, focused on detecting changes in forest mosaics at a landscape scale:

Determine the nature of, and changes in, the forest mosaic at landscape scales--

- the extent of broad-scale disturbances (such as crown fire or insect outbreaks)
- the nature of gap and patch dynamics
- changes in patch and gap size through time
- ecotonal shifts
- extent of certain land-use changes
- broad-scale shifts in forest patch age
- forest fragmentation

See forest dynamics model (Figure I- 19) and discussion for more information about the sensitivity of forest dynamics to changes in fire and climate regimes.

Phenology
Phenological studies have indicated that in much of the West, lilacs and honeysuckles are responding to recent warming trends by blooming and leafing out earlier (Cayan et al. 2001). Human-influenced temperature patterns are significantly associated with discernible changes in plant and animal (invertebrate, bird, amphibian, tree, shrub) phenological traits (Root et al. 2005). A national phenological monitoring network may be initiated, and recommendations on different approaches to monitoring phenological change in parks will be distributed soon from a recent NSF-funded workshop (J. Gross, personal comm.)

Indicators of Change related to Climate and Fire

Landscape composition and pattern

Landscape patterns or mosaics are primarily influenced by abiotic constraints (elevation, soil, microclimate, topography), biotic processes (demography, competition, dispersal), and disturbance regimes (Urban et al. 2000). Vegetation forms a primary and dynamic component of landscape pattern. Its relationship to climate and fire (two major drivers of change in the Sierra Nevada), and its importance as wildlife habitat make it a critical landscape element to monitor.

We know from historic photos and other research on vegetation change and fire history that, over the past 150 years, there have been significant changes in landscape mosaics (patterns of vegetation) in the Sierra Nevada. Changes in these landscape mosaics can be readily observed in repeat photographs (Figure I- 12). Sierra Nevada research on vegetation change (Vankat 1970, Vankat and Major 1978, Parsons and DeBenedetti 1979, Roy and Vankat 1999) and fire history (Kilgore and Taylor 1979, Swetnam et al. 1992, Swetnam 1993b, Caprio and Swetnam 1995) has demonstrated strong links between vegetation structure and composition, fire, and climate.

Figure I- 12: Repeat photos of Middle Fork of the Kaweah River, Sequoia National Park. Evident in these photos is the change from shrub land to conifer forest over large areas—likely related to a decrease in fire frequency. 1900 photo is by George Smith and 1993 photo is by Nate Stephenson.

Fire Regime Attributes

Please see fire regimes model (Figure I- 13).

Fire Regime Attributes and Ecosystem Properties

(*Text Adapted from Caprio–in NPS 2003*)

Attributes of pre-Euroamerican fire regimes can provide vital reference information for understanding changes in ecosystems over the last 150 years and in developing goals for the restoration of fire. The concept of a fire regime allows us to view fire as a multi-faceted variable rather than a single event within an ecosystem (Whelan 1995). Thus areas can be classified as having a certain type of regime that summarizes the characteristics of fires, within some range of variability that can have both spatial and temporal attributes. Fire regimes are normally defined according to specific variables including frequency, magnitude (intensity, severity), size, season, spatial distribution, and type of fire (Gill 1975, Heinselman 1981). These fire regime characteristics may vary through time and across the landscape in response to climatic variation, number of lightning ignitions, topography, vegetation, specific historic events, and human cultural practices (SNEP 1996).

A graphic overview of fire regime attributes and affected ecosystem properties is provided in Figure I- 13. Fire regimes are also tightly linked to climatic variation (Swetnam 1993b). Predictions for increased fire severity and size in the Sierra Nevada with global warming (Torn and Fried 1992, Miller and Urban 1999a) suggest that monitoring of fire regimes and their effects on the ecosystem will be essential in enabling managers to adapt to and mitigate for changing conditions.

Following are descriptions of fire regime attributes depicted in Figure I- 13.

Frequency

Fire frequency is usually defined as the number of fires per unit time, or the mean fire return interval (mean number of years between fires). General patterns of pre-Euroamerican fire frequencies are apparent at several scales within the parks. Variation exists locally, with specific site characteristics such as productivity, potential for ignition, or other factors influencing frequency. General patterns are also apparent at large scales. For example differences in fire frequency are observed in different vegetation types (Figure I- 14). Additionally, on the west slope of the Sierra, frequencies reconstructed using fire-scarred trees show an inverse relationship between number of fires and elevation (Caprio and Swetnam 1995, Swetnam et al. 1998, Caprio 2000). Fire return intervals are longest at higher elevations, shortest in lower mixed conifer forest and appear to again increase in length in lower elevation grass-oak woodland and chaparral vegetation (Figure I- 14) (Caprio and Swetnam 1995, Caprio and Lineback 1997). Additionally, within at least some watersheds strong differences in fire frequency exist between aspects, with fire frequencies being higher on south aspects than on north aspects (Kilgore and Taylor 1979, Caprio 2000).

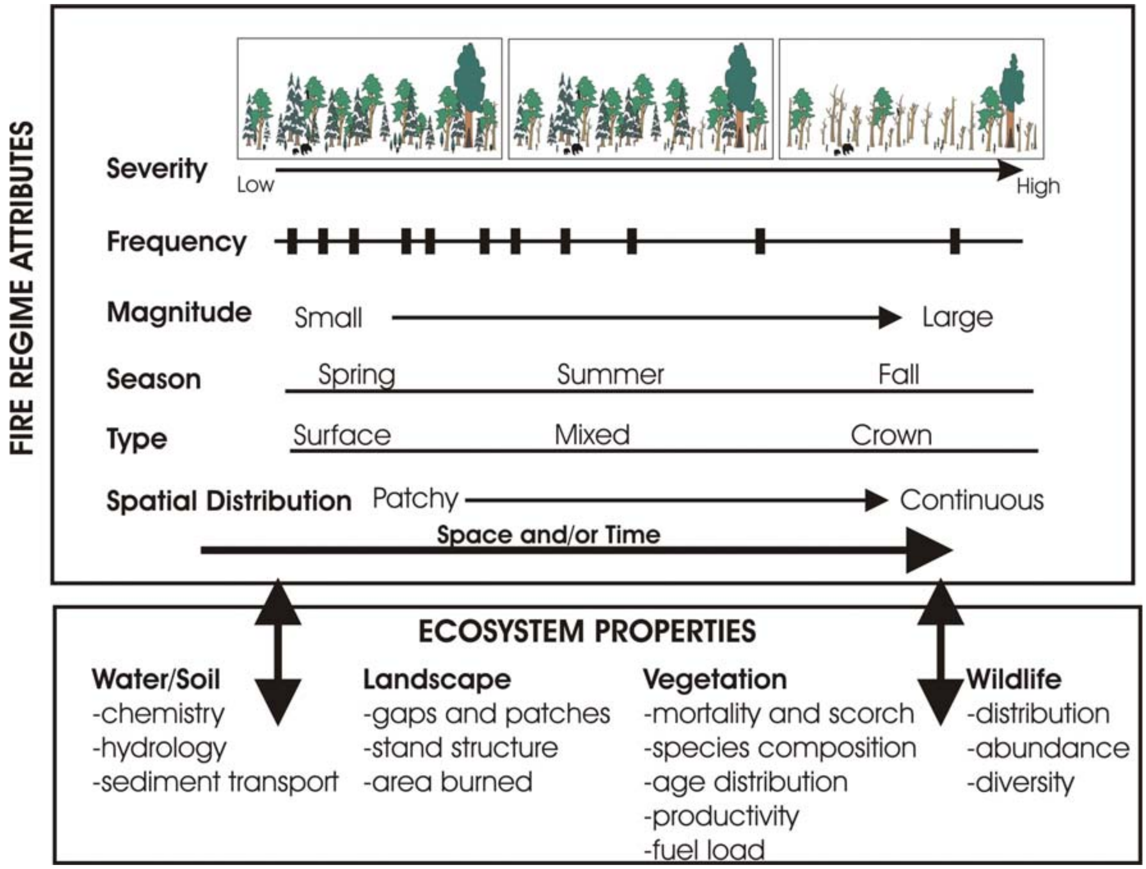


Figure I- 13: Fire regime attributes and selected ecosystem properties influenced by fire.

Magnitude

Fire magnitude characteristics, such as intensity and severity, also vary among vegetation types. Fire intensity is defined as the physical force (i.e., BTUs) of the fire per unit time (Pickett and White 1985), while severity refers to the impact of the fire on the organisms, communities or ecosystems (such as basal area removed) (Sousa 1984, Pickett and White 1985). Fire severity is closely related to weather, fuel load, size and distribution of fuel and moisture content of fuel and soil (Wright and Bailey 1982). It is a common indicator of fire effects on vegetation. An inverse relationship is often observed between disturbance size and/or severity and disturbance frequency (Sousa 1984, Pickett and White 1985, Swetnam 1993b).

At lower elevations, little is known about fire regimes in grasslands and oak woodlands due to the lack of fire scarred trees and replacement of nearly all native herbaceous communities by alien plants following initiation of intense grazing in the 1860s (Dilsaver and Tweed 1991). However, descriptions of vegetation suggest that episodic fast moving surface fires in flashy herbaceous fuels, during the dry summer/fall, probably played a role in these communities (Parsons 1981). Stand-replacing fire in chaparral communities today probably differs little from pre-Euroamerican characteristics, although frequencies have probably been altered. In much of the Sierra's sequoia-mixed conifer forest, fires were primarily non-stand replacing surface fires prior to Euroamerican settlement (Show and Kotok 1924, Kilgore and Taylor 1979, Warner 1980, Pitcher 1987, Caprio and Swetnam 1995). Fires in these areas were dominated by low to moderate severity, with high-severity generally restricted to localized areas (Stephenson et al. 1991a). Fire in red fir forest was typically non-stand replacing due to the fire resistant bark of this species (Pitcher 1981, 1987). Fire in lodgepole pine was generally a patchwork of low intensity surface fire and higher intensity crown fire depending of specific burning conditions.

Size

The scale of fire prior to Euroamerican settlement was significantly different from what is typically observed today. Both the frequency of fire occurrence and the frequency of large spreading fires were much greater than today or at any time in the last hundred years. Estimates based on fire history data suggest that from 15,100 to 24,700 acres burned annually within the parks (Caprio and Graber 2000). However, because of the vagaries of climate or number of ignitions, the actual number of acres burned in any given year could have been much greater or much smaller than the average.

Fire size was probably also related to overall landscape diversity patterns such as vegetation, fuel, and topographic complexity. In course-grained landscapes, such as the highly dissected, rocky high country (upper Kern and Kings River drainages), fires probably tended to be smaller with poor year-to-year synchrony. In contrast, fires were probably larger and more synchronous in fine-grained watersheds such as are found on the west side of the range. Burn patterns in these landscapes would be related to fire conductance among vegetation types and between drainages (Caprio 2003, National Park Service 2003).

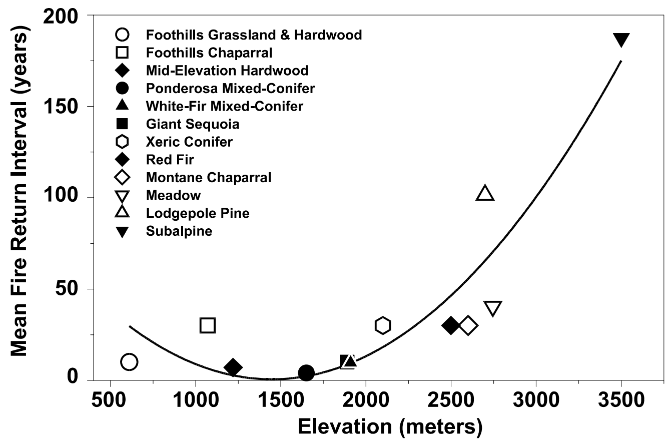


Figure I- 14: Relationship between fire frequency and elevation in Sequoia and Kings Canyon National Parks (from Caprio and Lineback 1997).

Season

Season of fire occurrence can have important effects on vegetation and wildlife. Factors that can be important in seasonality are fuel moisture content, phenology of vegetation, or life history patterns of wildlife. Vegetation and wildlife within particular ecosystems have generally adapted to fire within a particular window of time. Changes in seasonality that go outside the normal range of variability may have adverse impacts. In the Sierra Nevada, pre-Euroamerican settlement fires generally occurred from the summer through the fall, based on analysis of seasonal positions of fire scars in tree rings (Swetnam et al. 1992, Caprio and Swetnam 1995). This agrees with current knowledge of contemporary lightning ignition and fire spread patterns (Show and Kotok 1924, Vankat 1985), Sequoia Kings Canyon and Yosemite fire records).

Type

Fire regime types range from no fire, to surface fires and crown fires, with various combinations of fire types that depend upon vegetation, fuel characteristics, weather and topography. Common fire regime types for major SIEN park vegetation communities can be broadly defined as: (1) short-interval, low-intensity surface fires, (2) moderate interval, stand-replacing fires, (3) variable-interval, variable-intensity surface fires, (4) long-interval, low-intensity surface fires, (5) long-interval, high-intensity surface fires, (6) long-interval, variable intensity fires, and (7) lack of fire.

Spatial Distribution

The distribution of fire on the landscape at any given time is dependent upon many variables, including ignition source(s); topography; fuel continuity, structure and moisture; and weather conditions. Spatial distribution and pattern of fire are also dependent upon fire frequency and longer term climate patterns. High fire frequency periods probably had small patchy fires and resulted in a fine-grained pattern in vegetation and fuels, while low fire frequency periods had wider spreading fires that created a coarser grained landscape pattern (Swetnam 1993b). Fire and forest dynamics modeling efforts for the Sierra Nevada have suggested that fire can increase heterogeneity in some forest characteristics (variability in species composition) and also alter spatial heterogeneity (light regime within forest more variable with fire) (Miller and Urban 1999b). Fire suppression likely has created more homogeneous forests, through fuel accumulation and increased density of understory trees (Vankat and Major 1978), making forests more susceptible to larger, more severe fires.

Potential Fire Regime Indicators

To monitor fire regimes as a process, landscape-scale monitoring of key attributes of fire regimes will be needed. Fire severity, size, season and spatial distribution are all potential indicators that could be monitored through a combination of on-the-ground fire monitoring, remote-sensing and GIS analysis. Some of these attributes are already being monitored in SIEN parks (National Park Service 2003, 2004), and collaborative planning with park fire management will be needed to determine how the vital signs monitoring program can enhance and integrate with existing efforts. While the vital signs program does not propose to explicitly monitoring fire effects on ecosystem properties, many of our selected vital signs (water chemistry, hydrology, forest stand population dynamics, bird populations) will be affected by fire occurrence.

Bird Populations

Model and text by Sarah Stock, Wildlife Biologist, Yosemite National Park

Background

Sierra Nevada Network parks provide birds with over 658,000 hectares (1,600,000 acres) of unusually diverse habitats, ranging from gently sloping foothill grasslands, through chaparral/oak woodland and giant conifer forests, up to windswept alpine meadows and peaks. While none of the approximately 200 bird species that breed, winter, or migrate through the Sierra Nevada are unique, the key to its exceptional bird diversity is its extreme elevation gradient and corresponding habitat diversity. The western slope's elevation gradient spans over 14,000 feet – from the lower foothills to the top of Mt. Whitney – and supports the most diverse assortment of terrestrial habitats and birds in California (Beedy 1985). Accordingly, climate varies dramatically from the mild winters and hot dry summers that characterize the foothills, through wetter and cooler mid-elevations, up to harsh long winters and short summers in sub-alpine and alpine areas. Since birds are inextricably tied to the passage of seasons, species occupying different elevations follow radically different annual schedules. In recognition of the Sierra Nevada's bird diversity and critical breeding, stopover, and wintering habitats, Sequoia, Kings Canyon, and Yosemite National Parks, and a few other large areas in the Sierra Nevada, have been designated by the American Bird Conservancy as "Globally Important Bird Areas."

Status

Many populations of birds and other species are now threatened or endangered, or will likely become threatened soon, as a result of anthropogenic climatic and environmental changes (Terborgh 1989). The improved ability of scientists to document species population trends has led to long-term monitoring programs to monitor the health and status of populations, and to investigate the causes of observed population changes. North American Breeding Bird Survey data indicate that numerous bird species exhibit declining long-term population trends in the Sierra Nevada region. Data from the Sierra Nevada Network MAPS (Monitoring Avian Productivity and Survivorship) program in the parks' meadow habitats have shown declines in many breeding populations of birds. Analyses reveal negative trends in 13 species; and, adult birds of all species (pooled) represent a highly significant decrease, suggesting that populations of landbirds in Yosemite have been reduced by 23% over the last 13 years (Pyle et al. 2006). Over half the declining species exhibited low reproductive success, indicating that population dynamics on their Sierra Nevada breeding grounds is a limiting factor to these species' survival.

Stressors

Researchers have identified five main categories of stressors faced by landbirds in the Sierra Nevada Network parks (DeSante 1995, Graber 1996) SIEN Bird Workgroup 2006, pers. comm.) (Figure I- 15): (1) anthropogenic climate change (2) habitat fragmentation, loss, and insularization, (3) atmospheric pollution, (4) altered fire regime, and (5) invasive species.

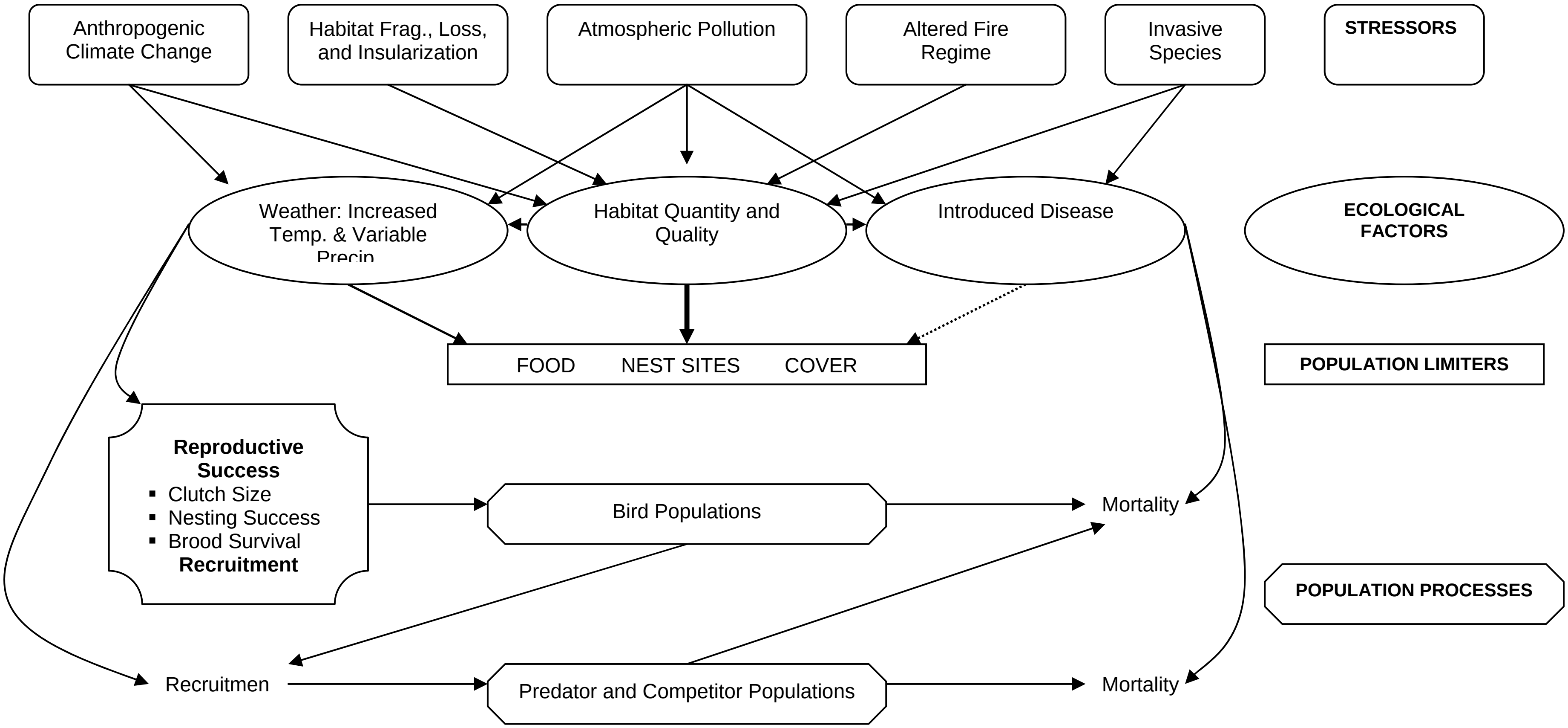


Figure I- 15. Bird populations conceptual model. Stressors, ecological factors, population limiters, and population processes affecting bird populations.

Anthropogenic Climate Change — Over 140 studies have shown that global warming is correlated to biological change and several of these studies have revealed that as temperatures increase, the geographical ranges of numerous species have shifted poleward or moved to a higher elevation (Root et al. 2003, Root et al. 2005). Concurrent with these studies, the recent Grinnell resurveys across the Sierra Nevada detected many landbird species ranging higher in elevation than observed 80 years earlier by Grinnell and his colleagues.

Habitat fragmentation, Loss, and Insularization — Habitat fragmentation and loss, including increasing exurban development with its concomitant increases in land conversion, is one of the biggest problems faced by landbirds today, and has contributed to the majority of species declines (Neotropical Migratory Bird Conservation Act 2000). The most endangered songbird in the Sierra Nevada, the Willow Flycatcher, is rapidly disappearing because of land use practices (e.g., grazing, agriculture) that have denuded or destroyed their riparian habitat. Habitat degradation on a regional scale probably affects the viability of bird populations on relatively intact habitats managed inside the parks. Nearctic-Neotropical migratory passerine birds are exhibiting the most severe population declines because they face habitat destruction and degradation during migration stopover and on both wintering and breeding grounds.

Atmospheric Pollution — The deposition of atmospheric pollutants in California's Sierra Nevada Mountains has resulted in the degradation of ecosystems (Duriscoe 1987, Unger 1989) and is thought to play a role in the declines of several wildlife populations (Davidson 2004, Fellers et al. 2004). Environmental pollutants, such as organophosphorous pesticides and ozone, travel upslope from the heavily developed San Joaquin and Sacramento Valleys due to prevailing winds (Zabik and Seiber 1993, LeNoir et al. 1999, Fancy and Gross 2004). The pollutants enter the Sierra Nevada ecosystem via wet and dry deposition, ultimately making their way into the food chain (LeNoir et al. 1999).

Altered Fire Regime — The Sierra Nevada ecosystem was historically dependent upon frequent fire. Fire created complexity across the landscape by opening forests for shrub communities and creating snags, logs, and a varied-age plant structure - all critical features that support diverse and abundant wildlife. Fire exclusion from the Sierra Nevada has contributed to long-term shifts in habitat composition and structure (Gruell 2001) which has negatively affected a diversity of landbirds, for example, Olive-sided Flycatcher which favor open forest with snags and scattered trees, Brown Creeper and Pileated Woodpecker which rely on older forests with large-diameter trees, and Black-backed Woodpecker which depends on burned forest.

Invasive Species — Invasive species include both introduced and native human commensal species that have expanded their range in the Sierra Nevada because of increased food supplies from stables, picnic areas, campgrounds, and residential areas. Introduced species, such as cavity nesting European Starling and House Sparrow, compete with native species for nest holes, and in some areas, such as Lee Vining Canyon, have reduced native populations of Violet-green Swallows, House Wrens, and

Mountain Bluebirds (Leland and Carter 1985, Gaines 1988). Native human commensals (native pest species) have increased historically, both in extent of range and abundance (Marzluff 2005) and include nest predators, the Brown-headed Cowbird, and generalist species. Nest predators, such as Common Raven, Steller's Jay, and Western Scrub-Jay, take both eggs and young from nests. The nest parasite, Brown-headed Cowbird, lays their eggs in the nests of small songbirds such as vireos, flycatchers, and warblers, who raise the cowbird young usually at the expense of their own. Generalist species include American Robin, Northern Mockingbird, and blackbirds which are more numerous near campgrounds and residential areas and eventually may limit the size of other native songbird populations if food and nest sites become limited resources.

Vital Sign

Landbirds are an appropriate indicator-species of local and regional change in terrestrial ecosystems because their ecology and biology integrates the effects of numerous stressors (Canterbury et al. 2000). Because of their high body temperature, rapid metabolism, and high ecological position on most food webs, birds are excellent integrators of the effects of local, regional and global environmental change on terrestrial ecosystems. Furthermore, their abundance and diversity in virtually all terrestrial habitats, diurnal nature, discrete reproductive seasonality, and intermediate longevity facilitate the monitoring of their population and demographic parameters (DeSante et al. 2005). Bird populations are a scientifically viable vital sign and surrogate for evaluation of network ecosystem condition for several reasons:

1) birds occupy a wide diversity of ecological niches in the parks;
2) birds are conspicuous, easily observable, and monitoring is cost effective;
3) as secondary consumers (i.e. insectivores), birds are sensitive indicators of environmental change
4) by managing for a diversity of birds, most other elements of biodiversity are conserved and bird monitoring can prevent future listing of declining species by identifying problems and solutions early;
5) knowledge of the natural history of many bird species has a rich basis in literature
6) all units in SIEN have a strong foundation of inventory data upon which to build future monitoring efforts
7) Monitoring Avian Productivity and Survivorship (MAPS) has occurred at all parks for varying numbers of years and time periods, including at one station in Yosemite (Hodgdon Meadows) for 14 years.

Measures. — Effective management of landbirds should include assessment and monitoring of vital rates (primary demographic parameters) as well as population trends (DeSante et al. 2005). Environmental stressors and management actions affect vital rates directly, usually without time-lags. Vital rates are essential for understanding a) the stage of the life cycle where population change is being effected, b) health and viability of populations, and c) habitat quality (DeSante et al. 2005). DeSante et al. (2005) identified six vital rates upon which management should be based: (1) productivity, (2) survival of young, (3) recruitment of young, (4) annual survival of adults, (5) site fidelity, and (6) immigration. By identifying proximate demographic cause(s) of landbird population changes, management guidelines may be formulated to reverse population declines and to evaluate the effectiveness of the management actions implemented.

Plant Invasibility Models

Sierra parks have been invaded by numerous non-native plant species. Some are well-known invaders in other areas (e.g., cheatgrass—*Bromus tectorum* in the Great Basin), and consequently we know about their invasion ecology and effects on invaded ecosystems (Gerlach et al. 2003). Others have not been well investigated, and their effects are relatively unknown. Thus, we usually treat each invasive species as if it has a unique ecology. Not all plant communities have been invaded by non-native plants (Gerlach et al. 2003). Furthermore, the qualities that make a plant community susceptible to colonization by non-native plants (i.e., *invasibility*) are not generally understood (Rejmanek and Richardson 1996). Our primary interest in monitoring non-native plants is to improve early detection of both new taxa that have not yet arrived in SIEN parks and new populations of non-natives that already occur in parks.

Although the ecology of invasion has received much attention in the last several decades, we still lack an all-encompassing theory of invasion (Davis et al. 2000, Davis and Thompson 2000), nor is there agreement on the terminology of invasion (Davis and Thompson 2000); (Daehler 2001); (Rejmanek et al. 2002). Here, we adopt the terminology of (Richardson et al. 2000) to describe the process of naturalization and invasion by non-native plants. The conceptual model we present is based on that proposed by (Davis et al. 2000).

The process of invasion can be most simply described as the sequential occurrence of three phases: introduction, naturalization, and invasion. *Introduction* means that the plant or its propagules have been transported across a significant geographical barrier. Many introduced plants may survive for short periods (called casuals or waifs) but do not persist unless repeatedly introduced. *Naturalization* occurs when introduced individuals reproduce regularly, overcoming any environmental or reproductive barriers, to establish a population sufficiently large that it is not subject to extinction by environmental variability. The length of time the population must persist to qualify as naturalized is not defined, but might be at least 25 years (see (Richardson et al. 2000), p. 99). Finally, *invasion* is the spread of the plant into areas distant from the site(s) of introduction. Invasion requires that the plant overcomes any barriers to dispersal in the new area, and can survive the abiotic environment as well as biotic interactions in the new area.

Introduction of species into the parks depends in part on whether surrounding communities (proximity of source) have been invaded, and on the vectors available to transport the plant (or its propagules) into the parks. Natural transport vectors, such as wind and animals, can move propagules into the parks. Plants or propagules may also be transported by human activities that import contaminated materials into the parks. These materials may include equipment, soil, sand, gravel, hay, straw, cultivated plants, car tires, and shoes.

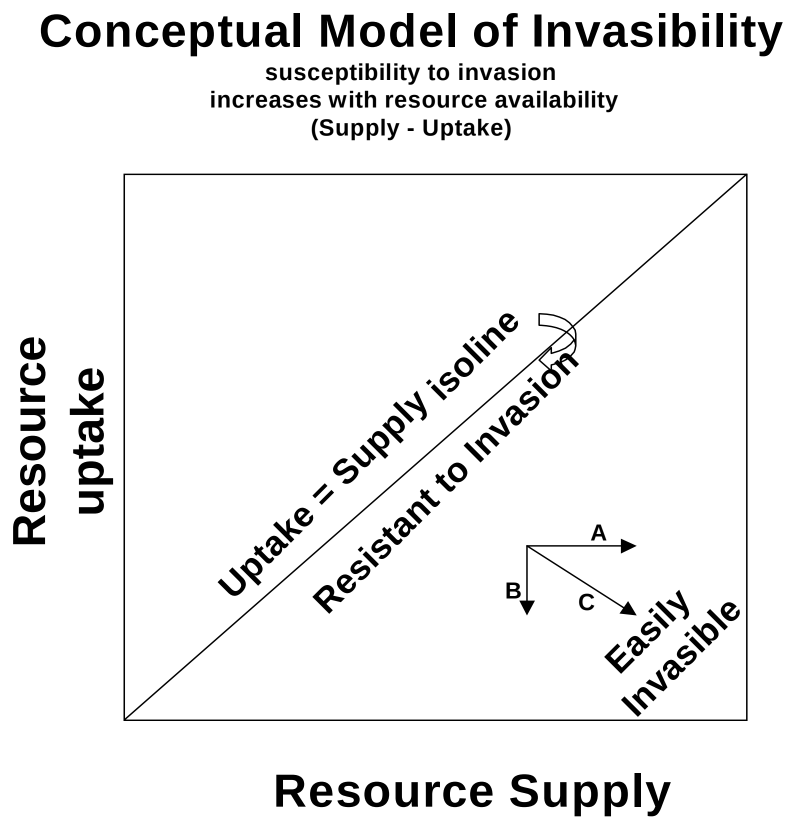
Once propagules or plants of potentially invasive species have arrived in parks, their naturalization, and subsequent invasion, may occur. Alternatively, propagules or plants may arrive in the parks from surrounding areas in which the invasive species is already naturalized. Thus, introduction to the parks can be considered invasion.

Our conceptual model of invasibility describes the process by which an exotic species may become established in an otherwise natural plant community. The model focuses sequentially on the roles of resource availability, temporal fluctuations in resources, and differences among communities in invasiblity.
The invasibility of a community (Figure I- 16 (Davis et al. 2000). For this model, we can consider the resources used by plants to be water, nutrients, and light. When resource uptake is very close to resource supply (the isoline on Figure I- 16), we expect competition to be strong and resource availability to be low. Thus, an invading plant would probably not persist. However, invasibility may increase if resources become more available. Resources can become more available either through an increase in supply (arrow A, Figure I- 16), a decrease in uptake (arrow B, Figure I- 16), or both.
There are many factors that may change resource availability. Those that may be important for Sierra Nevada plant communities are listed in Table I- 3.

Table I- 3. Factors that result in changes in resource availability and subsequently in invasibility of plant communities.

Factors that increase resource supply (arrow A)	Factors that decrease resource uptake (arrow B)
Increased precipitation – increased water supply	Decreased precipitation – decreased water supply
Climate change toward more moderate temperatures	Climate change toward more extreme temperatures
Fire – increased mineralization, reduced overstory (increased light on forest floor)	Fire – kills or maims plants
Nitrogen deposition – fertilizer effect	Excess pollution – toxicity
	Disturbances that kill or maim plants, e.g., increased herbivory, diseases, avalanches, grazing, floods

Although the spatial extent of most of the factors in Table I- 3 is very broad, some disturbances do act at local extents to decrease resource uptake. This might include natural perturbations such as gopher mounds and human-caused disturbances such as road edges and trails.



After Davis et al., 2000

Figure I- 16. Community invasibility: relationship to resource uptake and supply

As with factors that contribute to resource supply and uptake, resource availability usually fluctuates with time. Fluctuations in resource supply with season are likely to be overlain by shorter-term fluctuations due to local disturbances. Periods of greater resource availability typically lead to reduced competition, and thus represent “invasibility windows” for introduced species. See Figure 17. In this hypothetical example, uptake is near supply until a disturbance occurs that reduces uptake. This leaves a gap between supply and uptake for a period of time that defines an invasibility window.

Invasibility windows vary in magnitude (i.e., the difference between supply and uptake) and in length. Also, introduced species are likely to differ in the required thresholds of magnitude and length of the invasibility window necessary for the species to become naturalized. An invasible window for one species may not be for another species. In addition, if an introduced species requires resources at a higher level than are available in the invasibility window, it may not naturalize. For those introduced species that do naturalize, the frequency of occurrence of suitable invasibility windows must be sufficient for the species to complete the process of invasion by spreading to other sites. The spatial arrangement of these sites on the landscape may influence the ability of the species to spread (With 2002). For example, for a species that invades through disturbed habitats the extent and connectivity of these habitats must be sufficient to allow spread.

An application to Sierra Nevada plant communities contrasts hypothetical scenarios for two different plant communities: 1) a low elevation annual grassland and 2) a high elevation alpine fell-field (Figure I- 18). The annual grassland community of the Sierra Nevada is already much invaded with new species continuing to naturalize. This community has relatively high resource supply and favorable growing conditions (except for the hot, dry summer season). A disturbance during the growing season that drastically reduces resource uptake can leave a large invasibility window. Hypothetically, a larger invasibility window should allow a larger number of species to exploit that window. In contrast, the alpine community has a much lower level of resource uptake and supply than the annual grassland. A disturbance during the growing season (Figure I-18) decreases resource uptake, but not by the magnitude found in the annual grassland. The invasibility window in the alpine community is small compared to the annual grassland; thus, few introduced species are able to exploit it.

This conceptual model of invasion has some deficiencies. Foremost among them–it does not accommodate interactions among species other than competition. For example, it does not account for introduced species that have deleterious effects on their neighbors (allelopathy–see (Bais et al. 2003). Thus, it also fails to generalize to animal invasions, although the model is suitable for some aspects of animal invasions. Some invasive animal species exhibit aggressive behavior, which is not included in this conceptual model.

Conceptual Model of Invasibility
invasibility window in time and resource availability

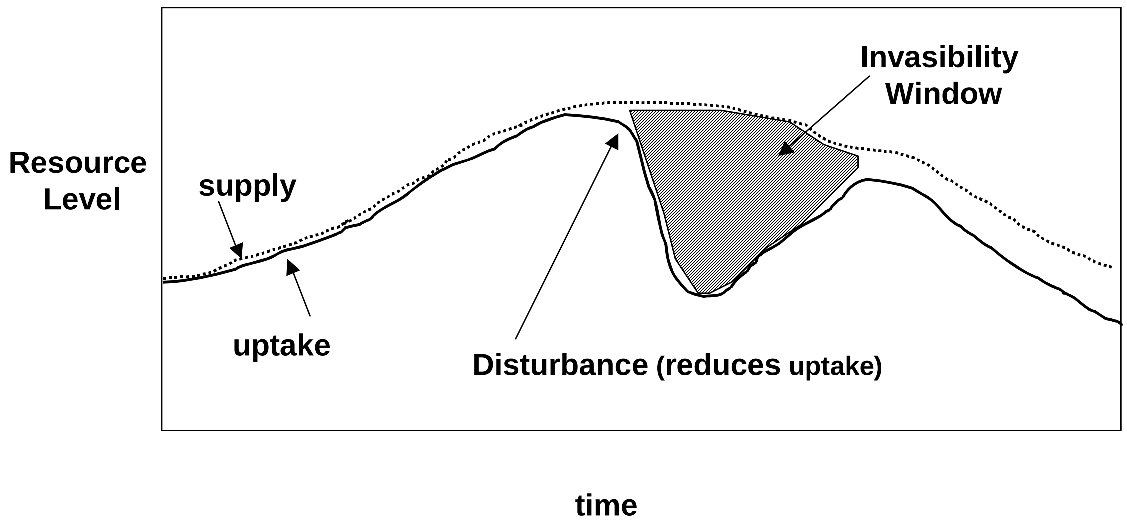


Figure I- 17. **Community invasibility: windows of invasibility in time.**

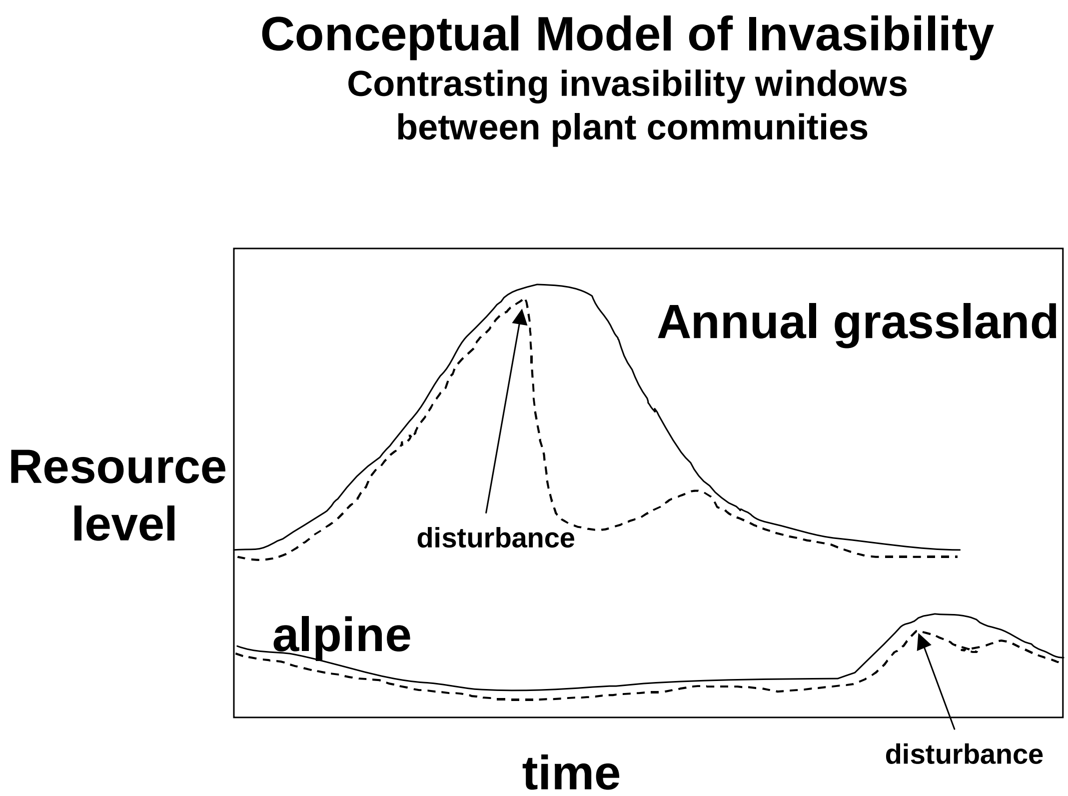


Figure I- 18. Community invasibility: contrasts between two plant communities that differ in resource levels.

Forest Dynamics

Montane and subalpine Sierra Nevada coniferous forests comprise one of the largest and most economically and ecologically important vegetation regions in California. This expanse includes most of the area of both slopes of the Sierra Nevada, from 600-1500 m at its lower margin, to 3000-3500 m at its upper limit (Rundel et al. 1988). At the lower elevation range, montane conifer forests are characterized by ponderosa pine, incense-cedar, white fir, sugar pine and black oak. More xeric sites are characterized by ponderosa pine-mixed conifer forests, while white fir-mixed conifer forests are found on more mesic sites, with scattered giant sequoia groves Above this zone, forming a transition to the higher subalpine forests, are the upper montane red fir, Jeffrey pine and lodgepole pine forests. The subalpine zone includes several geographically restricted forest types, dominated by mountain hemlock, western white pine, whitebark pine, foxtail pine, limber pine and western juniper (Rundel et al. 1988).

The Sierra Nevada Network has identified several forest types for potential long-term monitoring. As an example, we present a model of white fir-mixed conifer forest to highlight important ecosystem features, processes, and stressors that influence vegetation structure and composition in this forest type. Models for lower and higher elevation forest types will be similar, with different degrees of influence for fire, climate, insects/disease, invasive non-native species and management action/land use as agents of change affecting forest population dynamics, structure, and composition.

Forest tree population dynamics (seed fall, germination, recruitment, growth, and mortality) are highlighted in our forest dynamics model (Figure I- 19). Monitoring recruitment, growth, and mortality rates, along with causes of tree death, provides simple and well-understood metrics for quantifying and interpreting changes in forest tree populations in response to climate, fire, and other agents of change (e.g. insects, pathogens).

Physical Environment and Forest Dynamics

The steep elevation gradient in the Sierra Nevada has a strong influence on vegetation, climate, and fire patterns. In the conifer zone of the central and southern Sierra Nevada, most precipitation (around 95%) falls from October through May, and amount of snowpack is much more important than rain in determining soil water availability through the growing season. In the white fir-mixed conifer forests, moisture is more limiting to tree growth than temperature, as soil moisture usually declines throughout the summer and into fall while temperatures are still optimal for growth. High soil moisture availability in well-drained soils is believed to be the primary factor allowing sequoias to grow within present grove boundaries but not in adjacent mixed-conifer forest (Rundel 1969, 1972). Thus, undisturbed grove hydrology is critical to sequoia ecosystem sustainability (Stephenson 1996). In addition to elevation, slope aspect and soil depth are also important to forest distributions as explained by differences in water balance on north versus south slopes, and in deep versus shallow soils (Stephenson 1998).

Elevation is inversely related to fire frequency (Caprio and Swetnam 1995, Caprio and Lineback 1997), and aspect differences result in different fire frequencies within the same elevations in a watershed (Caprio 2000). More mesic conditions on north slopes result in higher fuel moisture, and thus fires on these slopes tend to occur and spread mostly in drier years, compared to south slopes at similar elevations.

Stressors on forest dynamics that can be categorized under physical environment include anthropogenic climate change and air pollution. Climatic change may alter forest dynamics directly by affecting growth, mortality and recruitment rates of trees. Reduced water availability may increase frequency of drought events. The effects of drought on various life cycle stages of trees are likely to be more acute when accompanied by other stressors such as air pollution and fire exclusion (Savage 1994). Research and observation suggest that summer-time desiccation is the main cause of death of giant sequoia seedlings (Harvey et al. 1980, Stephenson 1994), thus warmer, drier summers could reduce recruitment of giant sequoias and other conifer species. A long time period of warming and/or drying could result in actual shifts in tree species distributions upward in elevation.

High levels of ozone in the southern Sierra Nevada are known to produce foliar injury and premature needle abscission (Duriscoe and Stolte 1989, Miller et al. 1991) and growth reduction (Peterson et al. 1987) in ponderosa and Jeffrey pines. Ozone also affects photosynthetic rates and stomatal conductance in Jeffrey pine (Patterson and Rundel 1989). Giant sequoia seedlings were also demonstrated to have sensitivity (chlorotic mottle and leaf necrosis) to present ambient ozone levels and to 1.5X ambient ozone levels in fumigation experiments (Miller et al. 1992) . Ozone injury can lead to reduced root development in sequoia seedlings (Taylor et al. 1986), and this could prevent seedlings from being able to reach adequate subsoil moisture, critical to their survival in the first season of growth (Miller et al. 1992). In many cases, pollution weakens trees without being a direct cause of death (Savage 1994). Ozone damage may weaken trees’ resistance to disease and insect attack.

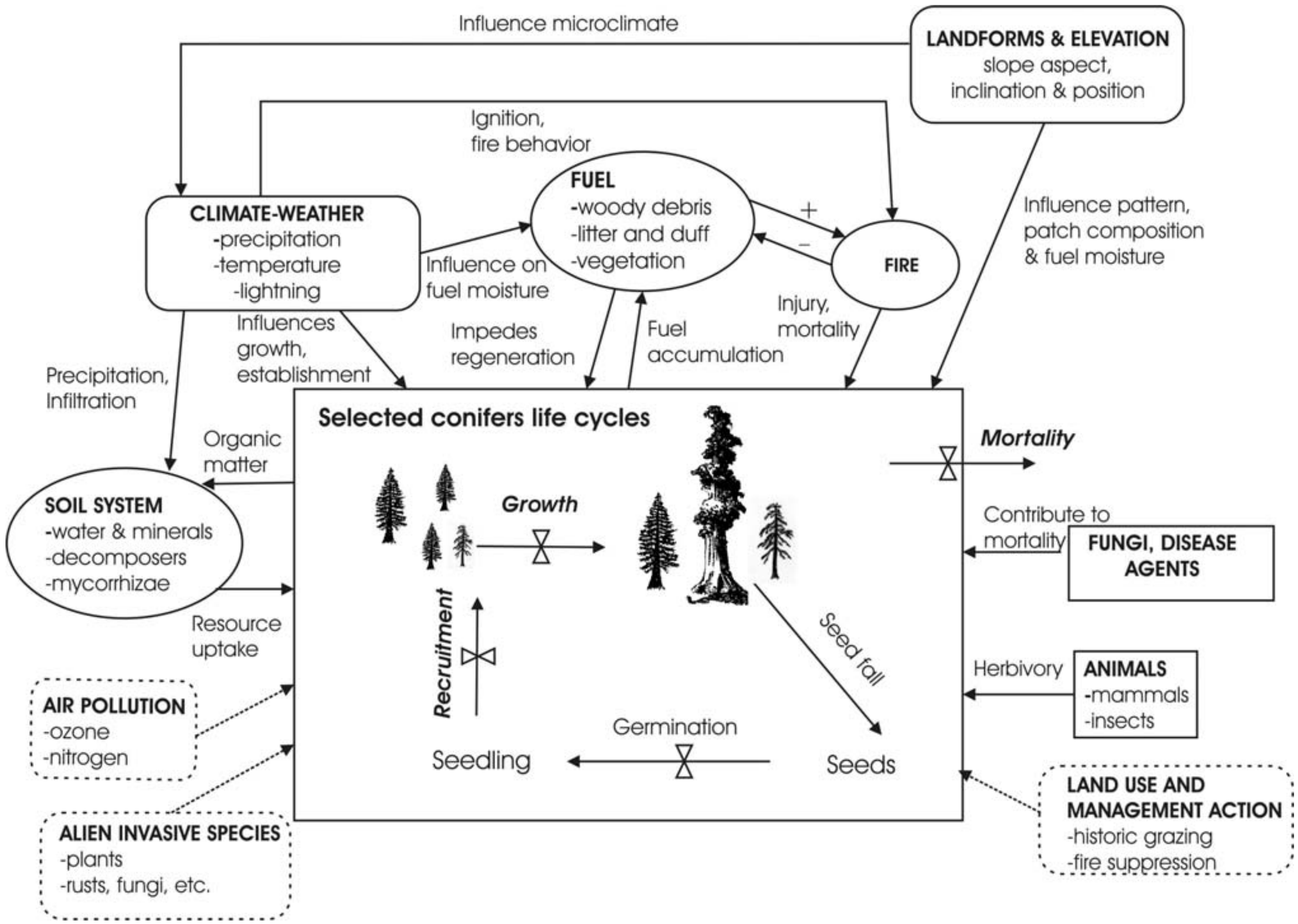


Figure I- 19. Mixed conifer forest model (adapted from (Vankat 2004), to emphasize forest population dynamics). Symbols are as follows: rectangles= biotic components, ovals=interactive controls, solid rounded rectangles = state factors, and dashed rounded rectangles = anthropogenic stressors. Text within symbols includes title (in bold) and important features. Lines are as follows: dashed lines = relationships involving anthropogenic stressors and solid lines = other relationships.

Biotic Influences on Forest Dynamics

A variety of native insects, rusts, fungi, cankers and parasitic plants are associated with tree disease and death. Sierra Nevada forest demography research has identified dwarf mistletoe (*Arceuthobium spp*.), fir canker (*Cytospera abietis*), and fir engraver (*Scolytus ventralis*) as commonly associated with mortality in fir species, and pine beetles (*Dendroctonus spp*.) as commonly associated with pine mortality (Parsons et al. 1992, Mutch and Parsons 1998). Occasional outbreaks of Douglas-Fir tussock moth (*Orgyia pseudotsugata*) occur, causing defoliation and mortality primarily in white fir. The non-native white pine blister rust (*Cronartium ribicola*) is an important factor associated with 5-needle pine mortality in the Sierra Nevada (Duriscoe and Duriscoe 2002) and elsewhere. Over the past 15 years, sugar pine deaths in Sequoia National Park associated with blister rust and stress (i.e., resource competition) were common, suggesting significant roles for both blister rust and fire exclusion in population trajectories (van Mantgem et al. 2004).

Alien plants do not currently represent a major problem in Sierra Nevada parks' white fir-mixed conifer forests. The return of fire through prescribed burning and allowing lightning-caused fires to burn has increased species richness in these montane forests (Keeley et al. 2003). However, the increased gap formation from fire also increases the potential for invasions of alien plants (Hobbs and Huenneke 1992, Keeley et al. 2003). In Sequoia and Kings Canyon National Parks, Keeley et al. (2003) found that aliens comprised only 0.3% of understory flora in unburned forests (unburned for at least 75 years) and 3.4% in burned forests. Disturbances created by timber harvest may result in many times greater alien composition (Battles et al. 2001). The invasive problem in central and southern Sierra Nevada forests centers primarily around cheatgrass (*Bromus tectorum*). *Bromus tectorum* has had drastic effects on fire regimes throughout the Great Basin (Mack 1981, Whisenant 1989), and there is concern that it could alter fire regimes in the Sierra Nevada as well (Keeley 2001). It is through altering fire regimes that invasive species are likely to have the most impact on montane forests. Other alien invasive species most commonly associated with burned areas in network white fir-mixed conifer forests include: bull thistle (*Cirsium vulgare*) and wooly mullein (*Verbascum thapsus*) (Demetry, pers. comm.).

Vertebrates that live in white fir-mixed conifer forests do not, at larger scales, have substantial influence on population dynamics of trees. Animal (deer, small mammals) browsing of foliage may have small, localized effects on tree reproduction and vigor. Squirrels and chipmunks feed on conifer seeds, with large pine seeds (sugar pine, ponderosa pine, Jeffrey pine) being the preferred type of food, and white fir and red fir seeds preferred over the very small incense-cedar and giant sequoia seeds (Harvey et al. 1980). Douglas squirrels (*Tamiasciurus douglasi*) harvest green giant sequoia cones as well as seeds from other conifer cones for food (Harvey et al. 1980). At local scales, and in low seed production years, rodents may have some influence on seed availability and regeneration success.

Fire Regime and Forest Dynamics

Detailed fire histories obtained from fire scars sampled on tree trunks, logs and snags in white fir- (and giant sequoia-) mixed conifer forests demonstrate that fire return intervals in these forests prior to the mid 1860s ranged from 1 to 30 years, with the mean fire interval ranging from 10 years to a more conservative maximum mean of 16 years (Kilgore and Taylor 1979, Swetnam et al. 1992, Swetnam 1993b, Caprio and Swetnam 1995, Swetnam et al. 1998, National Park Service 2003). Beginning in the 1860s, fire regime abruptly changed when human ignitions decreased with decline of Native American populations, and cattle and sheep grazing reduced fuel loads (Parsons 1981, Swetnam 1993b)((Vankat 1977). With the establishment of Sierra Nevada national parks in the late 19th and early 20th centuries, aggressive suppression of wildfires was initiated (Vankat 1977). In some forests, a pulse of tree reproduction followed the end of grazing: seedlings established in grazing-disturbed areas, domestic animals no longer trampled and ate seedlings, and fires were suppressed (Vankat and Major 1978).

A variety of studies suggest that past Sierran mixed conifer forests had lower tree density, and very different demographic distribution of age classes—with lower fuel loads and greater landscape diversity of forest patches than current forests (Parsons and DeBenedetti 1979, Bonnicksen and Stone 1982, Vale 1987, Ansley and Battles 1998, Roy and Vankat 1999, Stephenson 1999)((Vankat and Major 1978). While many of the changes observed in forest structure and function are thought to be primarily due to fire exclusion, they may also be related to warmer, moister conditions of the 20th century (Graumlich 1993, Scuderi 1993, Keeley and Stephenson 2000).

While the type of fire regime in white fir-mixed conifer forests (inclusive of giant sequoia groves) is often described as understory or low intensity surface fires, there is evidence from studies of forest age structure and post-fire giant sequoia growth response that low intensity fire interspersed with patchy high intensity fire is needed for successful recruitment of shade-intolerant giant sequoias seedlings (Harvey et al. 1980, Harvey and Shellhammer 1991, Stephenson et al. 1991b, Stephenson 1994, Mutch and Swetnam 1995). Stephenson (1994) estimates that a minimum of 0.1 ha gap size is needed for significant giant sequoia recruitment. In addition to favoring seedling establishment, patches of higher intensity fire result in release of more seeds from semi-serotinous giant sequoia cones. Other canopy dominants (sugar pine, Jeffrey pine) are dependent on gaps for effective regeneration, and the distribution of forest gap generated patches also likely has important effects on the distribution of wildlife (Keeley and Stephenson 2000). In general, a higher diversity of species composition, forest size structure, and landscape pattern occurs with a natural stand-thinning fire regime (Figure I-20).

Establishment of prescribed fire programs in Sierra Nevada parks in the 1960s has made substantial progress toward reducing fuel loads and modifying stand structure to reduce tree densities in many areas (Kilgore 1973, Keifer et al. 1995, Keifer et al. 2000). Lightning-caused fires cannot always be allowed to burn due to constraints of developments, air quality restrictions, proximity of neighboring lands with commercial timber, human-made barriers to fire spread, and staffing restrictions during busy fire seasons. Thus management-ignited fires will need to continue to play a significant role in restoring historic fire regimes to park landscapes (Keeley and Stephenson 2000).

Monitoring of forest dynamics will need to be linked to monitoring of fire regime and fire effects to enable effective interpretation of trends in tree population dynamics and large-scale forest landscape changes in pattern and structure.

While mid-elevation mixed conifer forests occupy a large area and contain focal species of interest for long-term monitoring (giant sequoia, sugar pine, Jeffrey pine), other forests of interest include those at the lower and upper elevation ranges, as these are areas that most likely to be sensitive to climatic change. Low-elevation forests in the Sierra Nevada are the most dynamic (highest turnover rates), and therefore may respond most quickly to environmental changes (Stephenson and van Mantgem 2005). High elevation forests may respond more slowly to a given unit or pace of climatic change, but model projections suggest that climate may change more rapidly at high elevations in the Sierra than at low elevations. Monitoring tree population dynamics and forest density at and near treeline also offers the opportunity to detect the beginnings of an upward shift in a highly climatically-determined ecotone.

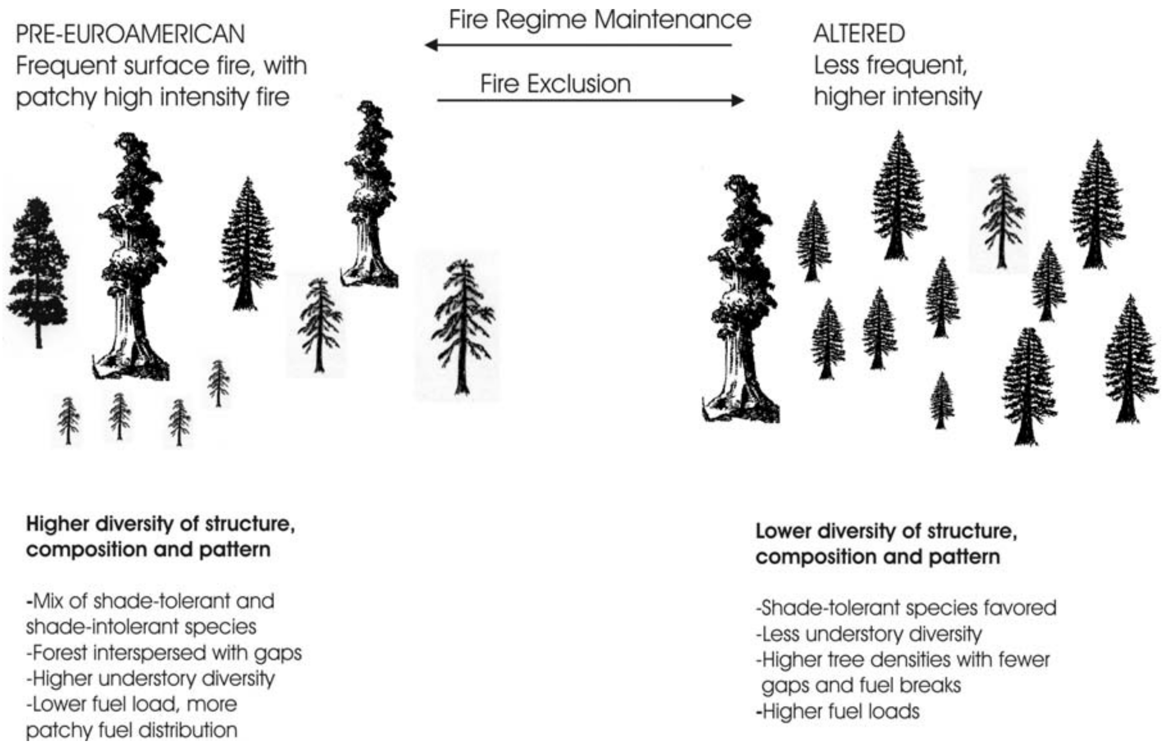


Figure I- 20. Fire regime effects on white fir-mixed conifer forest structure, composition and pattern. Alteration of the fire regime through fire exclusion results in the types of changes indicated above for Sierra mixed conifer forests.

Aquatic Systems

The Sierra Nevada parks protect a diversity of water resources, including over 4,500 lakes and ponds, thousands of kilometers of rivers and streams, seeps, wet meadows, waterfalls, hot springs, mineral springs and karst springs. Some of these aquatic systems have high biodiversity relative to the area they occupy in the parks (especially wetlands and meadows), some host endemic invertebrates (karst systems), and some provide habitat to sensitive and declining species (such as mountain yellow-legged frog in high-elevation lakes). Water dynamics in the Sierra Nevada are a critical component of both the parks' ecosystems and the larger California water infrastructure. The snow pack acts as a temporary reservoir, storing water that will be released during the warmer and drier months.

Rainbow Falls, Devils Postpile National Monument. NPS photo.

In this section, we describe the aquatic system components, processes, and drivers (including the anthropogenic stressors) to provide a general framework for the aquatic vital signs. We also provide draft models that focus in more detail on the aquatic biota and the relationships between biota and systemic stressors in the region.

General Aquatic Systems Model

The general model includes the main components of Sierra Nevada aquatic systems: lakes and streams, wetlands, groundwater, and snowpack, as well as the main processes and drivers (Figure I- 21). Hydrology of the Sierra Nevada is dominated by the winter wet, summer dry Mediterranean climate. Persistent winter snowpacks at higher elevations result in peak runoff in late May to early June. Runoff usually continues through the summer to supply flow to streams, but is typically very low by summer's end. Sierra Nevada ecosystems are adapted to drastic differences in water availability between seasons. As a result, temporal and spatial components of the hydrologic cycle are critical to these systems. Thus, hydrologic disturbances (drought, severe flooding) can have profound effects throughout the greater ecosystem.

We will first discuss four of the main components of the aquatic system: lakes, streams, groundwater, and snowpack. Wetlands will be discussed later in association with the Meadow/Wetlands model (Figure I-25). Next we will give an overview of the drivers of the aquatic system. Finally, we will use a hydrology model (Figure I-22) to discuss the major pathways and stores for water in Sierra Nevada ecosystems.

Sierra Nevada Lakes

High-elevation lakes are critical components of the parks' ecosystems, popular visitor destinations, and habitat for aquatic and terrestrial organisms including declining amphibian species. Lake ecosystems were selected for monitoring because they are valued for their ecological importance, recreational opportunities, and importance to regional water supplies, are threatened by multiple stressors and are sensitive to change. We will be monitoring three vital signs at high-elevation lake ecosystems: water chemistry, surface water dynamics, and amphibians.

The majority of Sierra Nevada Network lakes are located in the higher elevations (i.e. above 2500 m). Though a few lakes exceed 28 ha, most are only a few hectares in size and vary in depth from about 0.3 m to over 30 m. Sierra Nevada lakes are very dilute and characterized as oligotrophic, especially in the sub-alpine and alpine basins where there is sparse vegetative cover, shallow soils, and small contributing area. Sierra Nevada lakes have some of the lowest acid neutralizing capacity (ANC) concentrations in the western U.S. (Eilers et al. 1989).

Despite the low nutrient concentrations, these lakes still support a variety of aquatic fauna including zooplankton assemblages, micro-crustaceans, macro-invertebrates, fish (primarily non-native), and amphibians (Boiano et al. 2005). Two amphibian species, mountain yellow-legged frog (*Rana muscosa)* and Yosemite toad (*Bufo canorus*), are candidates for listing as 'endangered'. See Figures I-23 and I-24 and associated discussion for more information on aquatic biota.

Sierra Nevada Streams and Rivers

SIEN parks span seven major watersheds: Tuolumne, Merced, San Joaquin, Kings, Kaweah, Kern and Tule. Runoff from these watersheds drains into the San Francisco Bay/Sacramento–San Joaquin Delta in the north and the Tulare Lake Basin in the south. Yosemite, Sequoia, and Kings Canyon parks contain most of the headwater streams. Devils Postpile National Monument is located within the upper Middle Fork of the San Joaquin watershed. The headwaters of the Middle Fork of the San Joaquin begin 14.1 km upstream of the monument at Thousand Island Lake. The watershed area above the monument is managed by Inyo National Forest.

The SIEN plans to monitor water chemistry and surface water dynamics (or flow) in selected streams and rivers. Stream flow (or discharge) is the most fundamental aspect of watershed hydrology. Flow in Sierra Nevada rivers and streams is highly variable in time, both within and between years. Peak flows can be up to five orders of magnitude greater than minimum flows. Annual volumes can be twenty times greater in very wet years than in very dry years (Kattelmann 1996). Some smaller streams cease flowing during prolonged dry periods.

High water levels are an integral feature of Sierra Nevada Rivers and have a variety of effects on aquatic biota as well as channel morphology (Erman et al. 1988, Kattelmann 1996). Peak flows in the Sierra Nevada result from snowmelt, warm winter storms, summer and early-autumn convective storms, and outbursts from storage (Kattelmann 1990). In rivers with headwaters in the snowpack zone (true of all SIEN rivers), snowmelt floods occur each spring as periods of sustained high flow, long duration, and large volume. Midwinter rainfall on snow cover has produced all the highest flows in major Sierra Nevada rivers in the past century (Kattleman et al. 1991). The last such flood of this type with high impacts to SIEN parks' infrastructure and aquatic systems occurred in January 1997 (see photo below).

Yosemite Valley campground during January 1997 flooding of the Merced River. Photo by Steve Thompson.

At the other extreme, stream flow in Sierra Nevada rivers can become quite low during intense or extended droughts. The past two decades have included record droughts for one year (1977), two years (1976-1977), three years (1990-1993), and six years (19987-1992). Total stream flow averaged across many Sierra Nevada rivers was about half of average in each case (Kattelmann 1996). Changes in precipitation type and timing that are expected with climate change will result in longer and drier summers with less water available for ecosystems and regional economic uses.

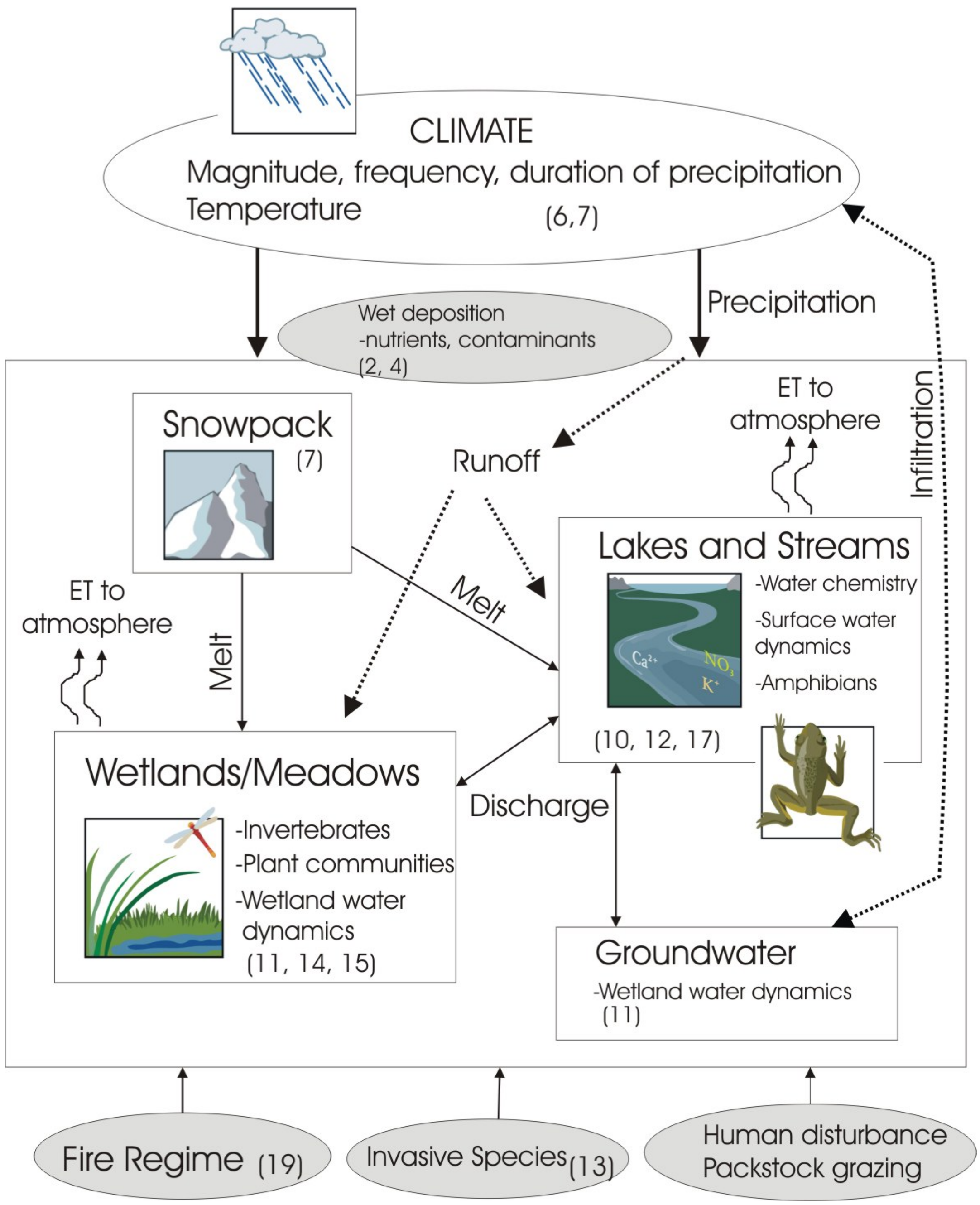


Figure I- 21. Aquatic Systems Conceptual Model. The three main systems shown include lakes and streams, wetlands, and groundwater, with snowpack serving as a temporary reservoir feeding the other systems seasonally. Drivers (including anthropogenic stressors) are shown in ovals. Vital signs are represented by lists of items in boxes, or by the numbers that cross-reference to Table I-2. Illustrations by Justin Hofman.

The Sierra Nevada is generally regarded as producing surface water of excellent quality, meaning the water is suitable for almost any use and contains lower amounts of contaminants than specified in state and federal standards. Most runoff would be suitable for human consumption except for risk of pathogens (Kattelmann 1996). Very little of the water of the Sierra Nevada can be considered highly polluted (i.e., contaminated with materials having potential adverse effects at concentrations above background level). Areas of lower water quality correspond to those areas with greater human activities and access. While SIEN park waters are of high quality compared to waters in agricultural and urban areas in the state, there are still a number of threats to park water quality that will be discussed in the Drivers section below.

Snowpack

Emerald Lake Basin, Sequoia National Park. NPS photo.

Snow is the dominant environmental factor in mountainous regions for more than half of the year. In the alpine and subalpine, snowpack protects vegetation from the abrasive and dehydrating effects of wind, and wind driven snow, effectively limiting the height of most woody vegetation to that of the snowpack. Sierra Nevada snowpack acts as a temporary reservoir, storing water until the spring snowmelt. It is then a primary source of water for the region, where reservoirs collect the snowmelt for gradual distribution to communities and agricultural needs. Recent modeling work predicts that the average temperature in California will increase 2.1°C by 2090, which will result in a loss of 43% of the April snowpack in the southern Sierra Nevada (measured as snow water equivalent; (Knowles and Cayan 2001, 2002).

Groundwater

Groundwater storage is generally limited throughout the Sierra Nevada compared with surface water resources. The geology of the mountain range is not conducive to storage of large quantities of subsurface water. Groundwater occurs in four general settings: large alluvial valleys; small deposits of alluvium, colluvium, and glacial till; porous geologic formations; and fractured rocks (Kattelmann 1996). The shallow aquifers tend to be highly responsive to recharge and withdrawals. The mineral content of groundwater is generally much higher than that of surface water, but are generally not an impediment for use (Kattelmann 1996). The only area where the SIEN plans to monitor groundwater levels is at meadows and wetlands associated with our meadow ecological integrity monitoring protocol. Groundwater dynamics are a critical driver in SIEN meadow and wetland systems, and are sensitive to both climatic change as well as local impacts (withdrawals for campground and other park infrastructure uses).

Drivers and Threats

Climate: Most atmospheric water in the Sierra Nevada originates as water vapor from the Pacific Ocean. This moisture is transported across California and precipitated as rain or snow. Rain is the dominant precipitation type at the lower elevations (less than 1,500 m) and snow is the dominant type at higher elevations (above 1,500 m). Warming climatic conditions have the most potential to alter snowpack storage; current models predict lower snowpack volume at mid-elevations (Knowles and Cayan 2001) and earlier melting at all elevations (Dettinger 2005b). Glaciers, which store water year-round, have been shrinking throughout the west for the past several decades (Basagic in progress).

Atmospheric Deposition: Contaminants and nutrients, produced from agricultural, urban, and industrial sources in the San Francisco Bay Area and the Central Valley, are transported by air currents into the Sierra Nevada where they are deposited as wet or dry deposition. Increased nitrogen deposition in the Transverse Ranges of southern California, low elevations in the southern Sierra Nevada, and high-elevations in the Colorado Rocky Mountains has already led to excessive leaching of nitrate into receiving waters (Fenn et al. 2003). Elevated nitrate concentrations in streams are a primary symptom of N-saturated ecosystems (Fenn et al. 1998). High elevation lakes and streams in the Sierra Nevada are especially sensitive to change from atmospheric deposition because the waters are oligotrophic and have a low buffering capacity. In addition, alpine watersheds have a low capacity to retain nitrogen primarily due to steep talus slopes, shallow soils, and sparse vegetation. Changes in nutrient cycles and shifts in phytoplankton communities in Sierra Nevada lakes have been detected and attributed to increased nitrogen and phosphorous inputs (Goldman et al. 1993, Sickman et al. 2003). Rates of nitrogen loss and their controlling mechanisms vary along the elevational gradient. Mid-elevation mixed-conifer forests, especially giant sequoia, are more effective at retaining nitrogen than ecosystems near the elevational extremes (e.g. chaparral and alpine) (Stohlgren 1988, Melack et al. 2002, Fenn et al. 2003).

Pesticides from the adjacent Central Valley (LeNoir et al. 1999) and global sources (National Park Service Air Resources Division 2003) have been detected in Sierra Nevada streams and lakes at all elevations. The extent of the effects on aquatic ecosystems is largely unknown; however, current research suggests that pesticides may be a threat to aquatic species, including declining amphibian populations (Sparling et al. 2001, Davidson and Shaffer 2002).

Fire: Over 100 years of fire suppression polices have altered fire regimes in the Sierra Nevada Network parks. In general, fire frequencies have decreased and the potential for higher severity wildfires has increased (Swetnam 1993a, Caprio and Lineback 1997, Caprio 2004). Potential effects on water resources from a lack of fire are reduced stream flows, changes in biogeochemical cycling and decreased nutrient inputs to aquatic systems (Chorover et al. 1994, Williams and Melack 1997b, Hauer and Spencer 1998b, Moore 2000). Less frequent but higher severity wildfires have the potential to impair water resources. Potential impacts include increased flooding, erosion, sediment input, water temperatures, and nutrient and metal concentrations (Tiedemann et al. 1978, Helvey 1980, Riggan et al. 1994, Mac Donald and Stednick 2003). Deposition of ash particles in the surrounding landscape may contribute to increasing nutrient inputs to oligotrophic waters (Spencer et al. 2003).

Since 1968 and 1970, Sequoia and Kings Canyon, and Yosemite National Parks have used fire extensively as a tool to reduce fuel loads and restore the natural processes of fire to park ecosystems (Caprio 1999). Although the parks' fire management programs made significant progress in the last 35 years, altered fire regimes are still considered one of the largest threats to the parks' ecosystems (Sequoia and Kings Canyon National Parks 1999a). Water quality research in the parks has focused on the effects of prescribed burning on hydrology, stream chemistry and nutrient cycles. Increases in stream flows and solute concentrations were detected following prescribed fires in headwater streams of Sequoia National Park (Williams and Melack 1997b, Heard 2005). However, solute concentrations were still well below levels that would threaten aquatic ecosystems. Long-term monitoring with repeated prescribed burning are needed to determine if these increases were within the natural range of variability. Effects of prescribed burning on stream flows or water quality have not been detected at the landscape scale (Heard 2005). The effects of a large, high-severity wildfire are likely to be more pronounced and detectable at larger scales.

Local Impacts

There are four large impoundments within Sequoia National Park. All four were built on existing lakes in the upper East Fork of the Kaweah in the early 1900s and are currently operated by Southern California Edison. Numerous small impoundments also exist in small creeks primarily used for water supplies. There are at least 18 water diversions and seven wells within the park boundary. Yosemite National Park contains two major impoundments: Hetch Hetchy (4.45×10^8 m^3) and Lake Eleanor (3.34×10^7 m^3). Hetch Hetchy, which impounds the Tuolumne River, was created in 1938 with the completion of O'Shaughnessy Dam. Hetch Hetchy Reservoir is part of the larger Hetch Hetchy Regional Water System that supplies drinking water to the City of San Francisco and irrigation water to the Central Valley. Lake Eleanor was created in 1918 and the water is used primarily for hydroelectric power. Cascades Dam, located on the Merced River downstream of Yosemite Valley since 1918, was recently removed and the river corridor restored. Numerous small dams and diversion are located throughout the park; most of these are associated with the High Sierra Camps.

SIEN parks have numerous wells for drinking water sources. Most of the larger wells are located in various developed areas in the parks. Groundwater pumping from wells located in Yosemite's Doghouse meadow and potentially other park fens are changing the soil and vegetation type in sections of these meadows (see Heard and Stednick, Appendix C).

Areas of general park operations or high visitor use are sources for nutrient and contaminant inputs to aquatic systems. Sources include sewage treatment plants, pack stations, campgrounds, roads, and popular swimming holes. Elevated concentrations of nutrients have been detected downstream of park spray fields (Sequoia And Kings

Canyon National Parks 1999b), and fecal coliform counts have been observed in popular Yosemite swimming holes (Williamson et al. 1996). However, at a larger scale, research in Sierra Nevada wilderness lakes and streams shows suggests concentrations of coliform and other human pathogens are very low (Derlet and Carlson 2002, 2003). Recreational and administrative packstock grazing in meadows within SIEN parks can affect aquatic systems through effects of trampling, erosion, and additional nutrients on wetland systems and adjacent lakes and streams.

Potential acid rock drainage from abandoned mines in the upper San Joaquin River watershed above Devils Postpile and in the Mineral King area of Sequoia National Park could degrade water quality in portions of these watersheds. Impacts on water quality have been observed from one mine in Sequoia. Impacts from other mines and cumulative impacts at a larger scale have not been quantified.

Hydrology Model

The hydrology model includes major pathways and stores for water in Sierra Nevada ecosystems. This model depicts four major water storage compartments: water or snow intercepted on the plant canopy, snowpack, surface water, and soil water.

Most atmospheric water in the Sierra Nevada originates as water vapor from the Pacific Ocean. Precipitation may be intercepted by a plant canopy or pass through to the ground (throughfall for rain, or snowfall). Intercepted precipitation may be evaporated from the canopy or drip through to the ground. Plant canopies have a finite storage capacity that may not be exceeded by very small precipitation events, thus most rainwater from those events may be evaporated. Conversely, precipitation events exceed the storage capacity of the plant canopy, and most precipitation falls to the ground. Changes in vegetation composition and structure will alter the canopy storage capacity, thereby affecting evaporation, throughfall, and snowfall rates.

Sierra Nevada snow pack is an important component of the hydrologic cycle because it is a natural reservoir that collects and stores water in the winter. The water is later released and available to ecosystems during the warmer and drier months. Loss of water from snowpacks is primarily by melting; however, sublimation (solid to vapor transport) also occurs under dry atmospheric conditions. Shortwave (solar) and long-wave (terrestrial) radiation are the main energy processes that contribute to snowmelt. However, rain-on-snow events can cause extensive and rapid melting, which can lead to flooding. The primary melting processes during these events are heat advection to the snowpack by rain, coupled with turbulent heat exchange between the atmosphere and snowpack (Dingman 2002).

Surface water describes any water on the surface that is free to flow, including overland sheet flow, streams, rivers, ponds, and lakes. Surface water is lost to evaporation, infiltration into the ground, and by overland flow (e.g., runoff). It may be gained through precipitation events, by overland flow (e.g., runon) from surrounding landscape elements, or by exfiltration of water from an underlying saturated substrate (e.g., a seep). Where surface water does not exist, think of that "model compartment" as storing zero water; thus, throughfall or snowmelt can directly infiltrate the soil. Infiltration of water into soil can be limited under two conditions. The first is that water arrives at the soil surface faster than the soil can absorb it. This results in standing water on the surface and the potential runoff of that water. The second condition limiting infiltration is when the underlying soil is at or near saturation. The lack of space for water storage hinders infiltration. In the higher Sierra where soils are sparse and thin, both mechanisms may operate to result in a high proportion of rainfall becoming runoff.

Soil water is gained by infiltration of surface water or by the rise of groundwater from below. Soil water is lost by evaporation, transpiration to the atmosphere, and by percolation to saturated soil below (groundwater). Evaporation of soil water is decreased by a cover of plant litter on the soil surface. Transpiration is the loss of water through the stomatal openings in plant leaves. Transpired water is replaced by soil water taken up through plant roots. Losses from transpiration are generally much larger than evaporative losses in Sierra Nevada ecosystems. This can give rise to the seemingly paradoxical increase in soil moisture when trees are removed from an area and bare soil is exposed to the elements. When calculating water balances, these two processes can be difficult to separate and are often considered together as evapotranspiration. Evapotranspiration is responsible for a significant 'loss' of water from the landscape. In the U.S., more than two thirds of precipitation is returned to the atmosphere by evaporation from plants and water surfaces (Dunne and Leopold 1978). Evapotranspiration is of high importance to plant growth and the main link between hydrologic cycle and ecosystems.

Soil water can flow laterally. The lateral flow of water in unsaturated soils is very slow compared to saturated flow, which in turn is very slow compared to overland flow of surface water. Numerous seeps and springs are fed by slow unsaturated as well as saturated soil water flow. Where unsaturated flow feeds into shallower soils those soils may become saturated and exfiltrate water to the surface.

We selected several vital signs that capture various aspects of the hydrologic cycle. These include surface water dynamics (i.e. streamflow, lake volume), wetland water dynamics (i.e. groundwater level, soil moisture, surface flows), meteorological parameters (i.e. precipitation, solar radiation, air temperature), snowpack (i.e. depth and water content), and landscape mosaics (i.e. glacial extent, snow cover).

Meteorological station in Sequoia National Park. NPS photo.

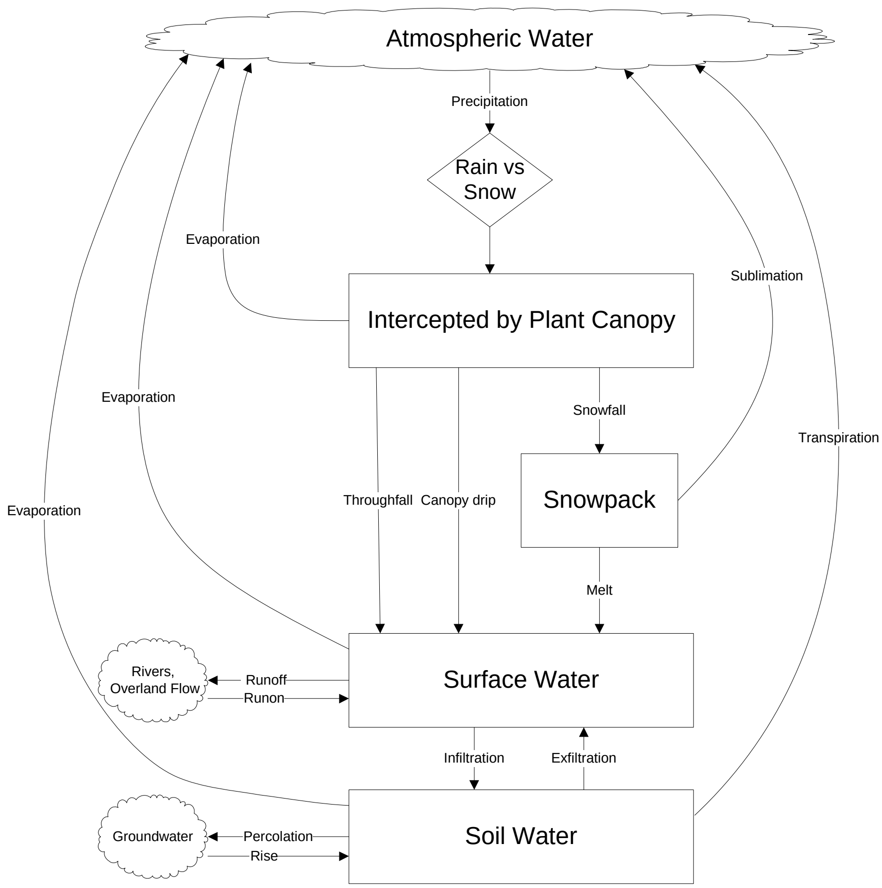


Figure I- 22. Hydrology model for Sierra Nevada.

Aquatic Biota

The Sierra Nevada Network (SIEN) aquatic biota (**Figure I- 23**) consist primarily of fish, adult and larval anurans, several snakes and birds, a few mammals, a number of aquatic vascular plants, benthic algae, zooplankton and phytoplankton (lakes), bacteria, fungi, protists, and a large and diverse invertebrate fauna. In addition, foothill rivers include one species of salamander and turtle. Some of the largest aquatic invertebrate taxa include larvae of mayflies, stoneflies, caddis flies, and various dipterans; adult and larval beetles; amphipods; several mollusks; mites; nematodes; flatworms, and annelids. The numerous invertebrate insect taxa metamorphose into adult terrestrial organisms that disperse beyond the wetlands to provide food to upland species as well as serve other terrestrial functions. Recent work (Holmquist, pers. com.) suggests that meadow wetlands are extremely productive and have a net export of food to upland areas.

While the above taxa occur in most SIEN waters, individual species' distributions vary with elevation. For example, large bivalves found in foothill streams (*Margaritifera* sp.) are represented by smaller bivalves in subalpine lakes (*Pisidium* sp.). The aquatic garter snake (*Thamnophis couchii*), which is common in the foothills, is replaced by the terrestrial garter snake (*Thamnophis elegans*) at high elevations. The mountain yellow-legged frog (*Rana muscosa*) occupies upper elevations of the parks, while foothill yellow-legged frog (*Rana boylii*) formerly occurred in the foothills (now extirpated). Conversely, the Pacific treefrog (*Hyla regilla*) occurs at all elevations.

Food webs within Sierra parks are complex. Aquatic invertebrates provide food for many of the vertebrate and invertebrate food chains. This includes both predation directly within the aquatic environment (e.g. dytiscids eating odonate nymphs) and predation on metamorphosed adults in the upland world (e.g. flycatchers eating mosquitos). Fish are one of the major predators of both aquatic and terrestrial insects. They collect insects drifting in the water column (e.g. Chironomidae) as well as terrestrial insects that can be taken near the water's surface (e.g. adult mayflies). At high elevations, mountain yellow-legged frogs play a significant role in the aquatic community. Besides being a major predator of metamorphosed insects and occasionally treefrogs, they are a source of food for other vertebrate predators like garter snakes (*Thamnophis elegans*), Clark's Nutcrackers (*Nucifraga columbiana*), and Brewer's Blackbirds (*Euphagus cyanocephalus*). Matthews et al. (2002) found a direct relationship between the abundance of garter snakes and mountain yellow-legged frogs.

Macrophytes (aquatic vascular plants), both submergent and emergent, provide multiple functions. In addition to providing basic photosynthesis and food for herbivorous fauna (e.g. meadow voles, Chironomids), macrophytes provide structure to aquatic habitat, cover for fauna, and substrate for periphyton (along with soil and rocks); they buffer erosion, absorb nuturients, and contribute organic detritus when they perish. This detritus provides food and habitat for aquatic insects (e.g. Baetidae).

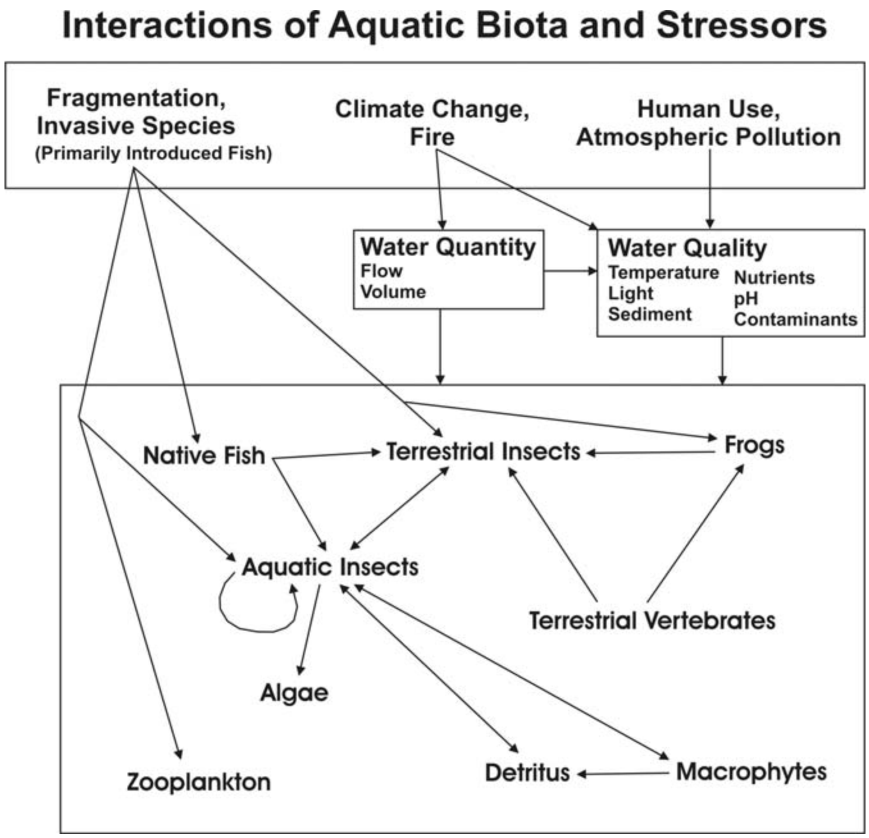


Figure I- 23. Principle interactions of aquatic biota and stressors, through effects on water quantity and quality, and other habitat effects such as introduction of non-native organisms (fish, disease) and fragmentation.

Aquatic systems are among the most altered ecosystems in the Sierra Nevada (SNEP 1996). Introduced alien invasive species caused much of this alteration. For over a hundred and thirty-five years, trout were planted in park waters, both in areas that contained native fish populations and in waters that were naturally barren of fish (Christensen 1977). The effects of these introductions on lentic environments have been to eliminate large zooplankton (e.g. *Hesperodiaptomus* sp.), (Stoddard 1987, Bradford et al. 1998) and open-water insects (e.g. Corixidae). When comparing streams with and without introduced trout, Herbst et al. (2003) found streams with introduced trout to have more and denser algae cover, more midges, and reduced density of *Doroneuria baumanni*, a stonefly that was probably the dominant predator prior to trout introductions. Native fish were impacted directly by competition with introduced brown trout (*Salmo trutta*) and eastern brook trout (*Salvelinus fontinalis*), and by genetic introgression from introduced genotypes of rainbow and golden trout (*Oncorhynchus mykiss*). Little Kern golden trout (*Oncorhynchus mykiss whitei*) became federally listed as threatened after being nearly extirpated by introduced trout. Knapp (2005) found an inverse relationship between the presence of introduced fish and garter snakes. This is likely due to introduced trout eliminating a major source of the garter snake's diet, i.e., mountain yellow-legged frogs. Introduced fish impacted the distribution and abundance of the mountain yellow-legged frogs (Knapp and Matthews 2000) by eating their larvae and some adults, by displacing frogs from deep lakes critical to their winter survival, and by fragmenting populations which destroyed functionality of their metapopulations (Figure I- 24).

Mountain yellow-legged frog. NPS photo.

In addition, mountain yellow-legged frogs have experienced dramatic population losses from a newly discovered fungus, *Batrachochytrium dendrobatidis*, which causes chytridiomycosis, a condition that destroys keratin in frog skin and results in death. This fungus was only discovered in the early 1990s, and the current available information suggests that it too has been introduced (Weldon et al. 2004, Rachowicz et al. 2005). The parks' waters receive considerable input from agricultural pesticides (Cory et al. 1970, Zabik and Seiber 1993, Aston and Sieber 1997, Datta et al. 1998, Datta. S. et al. 1998, McConnell et al. 1998, LeNoir et al. 1999, Angerman et al. 2002). We do not know whether or not these chemicals weaken a frogs' susceptibility to chytridiomycosis, but recent studies have showed endocrine disruption (Sparling et al. 2001, Fellers et al. 2004). Further, there exists an inverse relationship between pesticide use and downwind occurrence of frog populations (Davidson 2004).

While trout are the most prevalent of the introduced aquatic biota, they are not the only alien species of concern. Bullfrogs (*Rana catesbeiana*), introduced from eastern and central states, exist in several network parks. Bullfrogs threaten native turtles by eating their young (Jennings and Hayes 1994), and could impact future opportunities to restore foothill yellow-legged frogs (*Rana boylii*). An non-native amphipod (*Hyalella azteca*) was introduced into the Rae Lakes, and now they have become the most abundant species in plankton tows (Silverman and Erman 1979). On the North Fork Kaweah, *Potamogeton crispus*, a plant from Eurasia, has become common and may be competing with native *Potamogeton* sp.

Human use has also had measureable impacts to aquatic biota. Taylor and Erman (1979, 1980) found that growth of aquatic macrophytes and benthic invertebrates increased with increasing human use of lakes, and hypothesized that growth stimulation was from plant nutrients acquired from human presence.

As mentioned, SIEN parks have some of the worst air quality in the country (Peterson and Arbaugh 1992, Cahill et al. 1996). Among air contaminants, are ionic forms of nitrogen that contribute to episodic pH depression and to nutrient deposition in both upland and aquatic systems. Effects of acidification on aquatic systems were examined on aquatic systems in the Emerald Lake basin in the 1980s. In lentic environments, Sickman and Melack (1989) found no inhibition of phytoplankton growth above a pH of 4.0. Certain species of zooplankton (e.g. *Daphinia rosea* and *Diaptomas signicauda*) virtually disappeared when pH was reduced below 5.0, but density of certain other species increased with certain levels of acidification (e.g. *Kerotella taurocephala and Bosmina longirostris*), probably due to a lack of competition from *Daphinia rosea* (Melack et al. 1989). Melack et al. (1989) did not find a relationship between benthic invertebrates and acidification. In lotic environments, acidification down to pH levels between 4.6 and 5.2, for time periods of 6-8 hours, increased insect drift and the proportion of dead organisms within the drift (Hopkins et al. 1989, Kratz et al. 1994), though different taxa showed different levels of susceptibility and some groups showed no response to acidification (Kratz et al. 1994).

Changes in fire frequency and intensity affect sediment transport, water chemistry including nutrient dispersal, water quantity by altering evapotranspiration, and stream canopy cover which in turn affects light penetration and water temperature.
Chan (1998) found that increased fine sediment input caused by prescribed burns reduced macroinvertebrate diversity the following year.

Interactions of Frog (*Rana muscosa*) Populations and Stressors

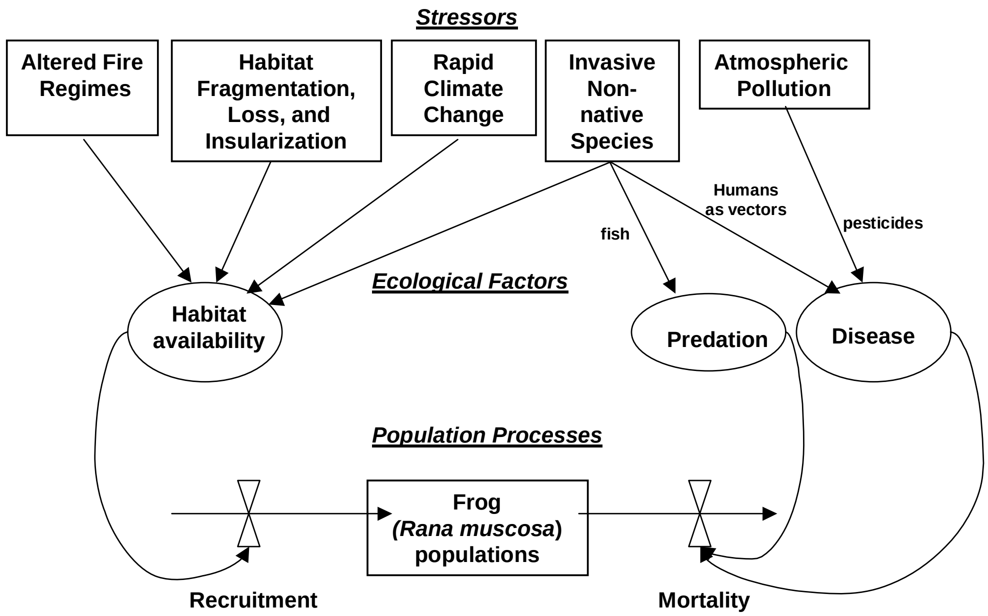


Figure I- 24. Principle interactions of mountain yellow-legged frog (*Rana muscosa*) populations and stressors shown in boxes.

Meadow/Wetland Systems

Meadows are diverse and complex ecosystems that vary widely in character and composition although they occupy only a small fraction of the land surface of the Sierra Nevada (Benedict and Major 1982, Ratliff 1982). Despite this variability, the processes that govern the creation and maintenance of meadows can be generalized into a simplified model. The meadow model illustrates the main ecosystem processes operating in Sierran meadows (Figure I- 25), and is a good basis for future models that may examine in more detail the effects of key drivers (climate, atmospheric deposition, invasive species) on meadow systems.

Meadows form in level to near-level catchments where soils are saturated for at least a portion of the year, as in basins formerly occupied by glacial lakes or along perennial stream courses. Sierran meadows range in size from small patches to large expanses, such as Tuolumne Meadow in Yosemite. Meadows generally occur above snowline, where snowmelt provides moisture during the summer growing season. In addition to surface flow, moisture enters meadows from streams and from sub-surface flows forced to the surface by local geomorphology. Meadows are characterized as wet, moist or dry, reflecting the relative availability of moisture during the summer growing season.

Big Wet Meadow, Kings Canyon National Park. NPS Photo.

Sierran meadow vegetation is dominated by perennial graminoids, which reflects the relatively short growing season of the middle and high elevations. Key genera include *Carex*, *Deschampsia*, *Calamagrostis*, *Juncus*, *Danthonia*, and *Eleocharis*, with species composition of individual meadows determined by local moisture regime and soil characteristics. Annual productivity of meadow graminoids is closely tied to the amount and timing of winter snows as well as changes in length of growing season associated with such fluctuation; when late lying snows shorten the growing season, productivity declines accordingly. In some wet and moist meadows, mosses are also important, forming mats and hummocks under favorable conditions. Woody plants are generally excluded from meadows because of seasonally saturated soils. However, willows (*Salix* spp.) are frequently found along stream channels and often form patches within meadows. Lodgepole pine (*Pinus contorta*), with a high degree of tolerance for saturated soils, is commonly encountered in and adjacent to meadows—taking hold during dry years and giving way to meadow vegetation under wetter conditions in a dynamic cycle of invasion and retreat.

Meadows provide critical breeding and foraging habitat for a suite of animal species. Recent work by Holmquist and Schmidt-Gengenbach in the Sierra Nevada Network parks (Holmquist and Schmidt-Gengenbach 2006) demonstrated the importance of meadows as breeding grounds for invertebrates, which form the energetic basis of many food chains (Figure I- 26). Many insects breed in meadows, then disperse into adjacent forests and woodlands as the season progresses. Invertebrates also serve as pollinators for montane and high elevation plants. A number of bird species, such as the federally endangered willow flycatcher, use meadows for foraging, nesting, or both. Mule deer take advantage of the cover provided by montane meadow vegetation by hiding their fawns under the dense herbaceous canopy. Small mammals, such as ground squirrels, pocket gophers, and voles, feed on both above- and below-ground meadow vegetation, and play a significant role in decomposition through soil perturbation. Animals such as frogs, toads, and shrews frequent the moist vegetation that edges stream channels.

Meadows are susceptible to the same stressors that affect the Sierran parks as a whole. Climate change has the potential to shift the species composition of mountain meadows through changes in the timing and amount of snowmelt and subsequent alteration of the underlying hydrology of local systems. Experimental manipulations in the Rocky Mountains demonstrate that increased temperatures can lead to a general drying down of mountain meadows, subsequent invasion by woody species such as sagebrush, influence carbon fluxes (Saleska et al. 1999), and cause shifts in timing of flowering of meadow species (Dunne et al. 2003).

Although Sierran high elevation meadows have so far proven to be relatively resistant to invasion by non-native plants (Gerlach et al. 2003), meadows in the lower montane are demonstrably susceptible to invasion by the non-native Kentucky blue grass (*Poa pratensis*), which now dominates some heavily grazed meadows in Sequoia and Kings Canyon National Parks (Neuman 1990, Gerlach et al. 2003). Dandelion (*Taraxacum officinale*), a common invader of mountain meadows worldwide, is also frequently encountered in disturbed meadows and riparian areas of the Sierra, especially in those that are heavily grazed.

Nitrogen pollution from atmospheric deposition has the potential to affect meadow vegetation productivity, and depending on seasonal timing, may affect aquatic organisms such as algae and microbes.

Although fire can impact meadows directly when vegetation is dry enough to burn, such events do not appear to lead to long-term changes (DeBenedetti and Parsons 1984). More long-lasting impacts are seen when stand-removing fires in adjacent forests are followed by increased flooding and surface erosion. This can lead to the deposition of sands and gravels during storm events and thus return the meadow vegetation to an earlier successional stage.

Meadow invertebrates are especially sensitive to fragmentation by trail corridors, with declines in species abundance and diversity observed as much as 2 meters away from trailbeds in seemingly undisturbed vegetation (Holmquist 2004) (Figure I- 26).

During the mid-1800s and into the early 1900s, most Sierran meadows were grazed, in some cases severely, by cattle and sheep. Many park meadows continue to be grazed by recreational pack stock, and this activity has a suite of known impacts to meadows such as soil compaction, erosion, trampling of vegetation, and changes in plant species composition (McClaren and Cole 1993). Recent research in Yosemite National Park suggests that even moderate levels of such grazing can have a measurable effect on meadow productivity (Cole et al. 2004).

The network is developing a protocol to monitor a set of three indicators of meadow integrity: meadow plant communities (including vascular and non-vascular plants), meadow invertebrates, and wetland water dynamics (groundwater and surface water).

Meadow and Wetlands Conceptual Model

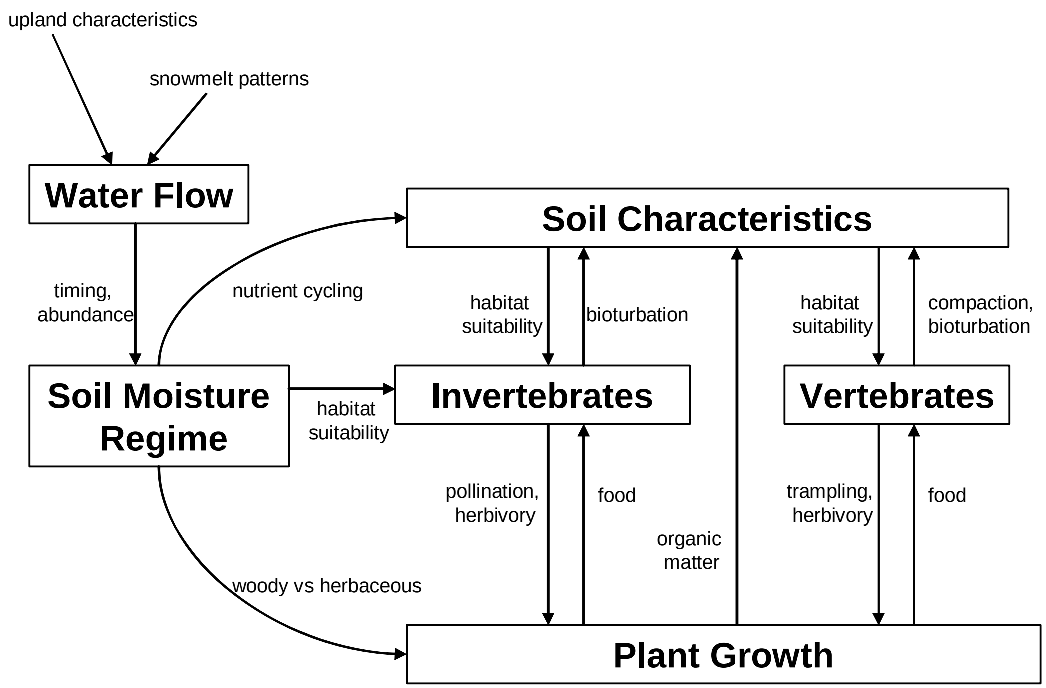


Figure I- 25. Meadow and wetlands conceptual model. [This model needs to be revised to incorporate major drivers, illustrate linkages between invertebrates and vertebrates and standardize it with systems other models].

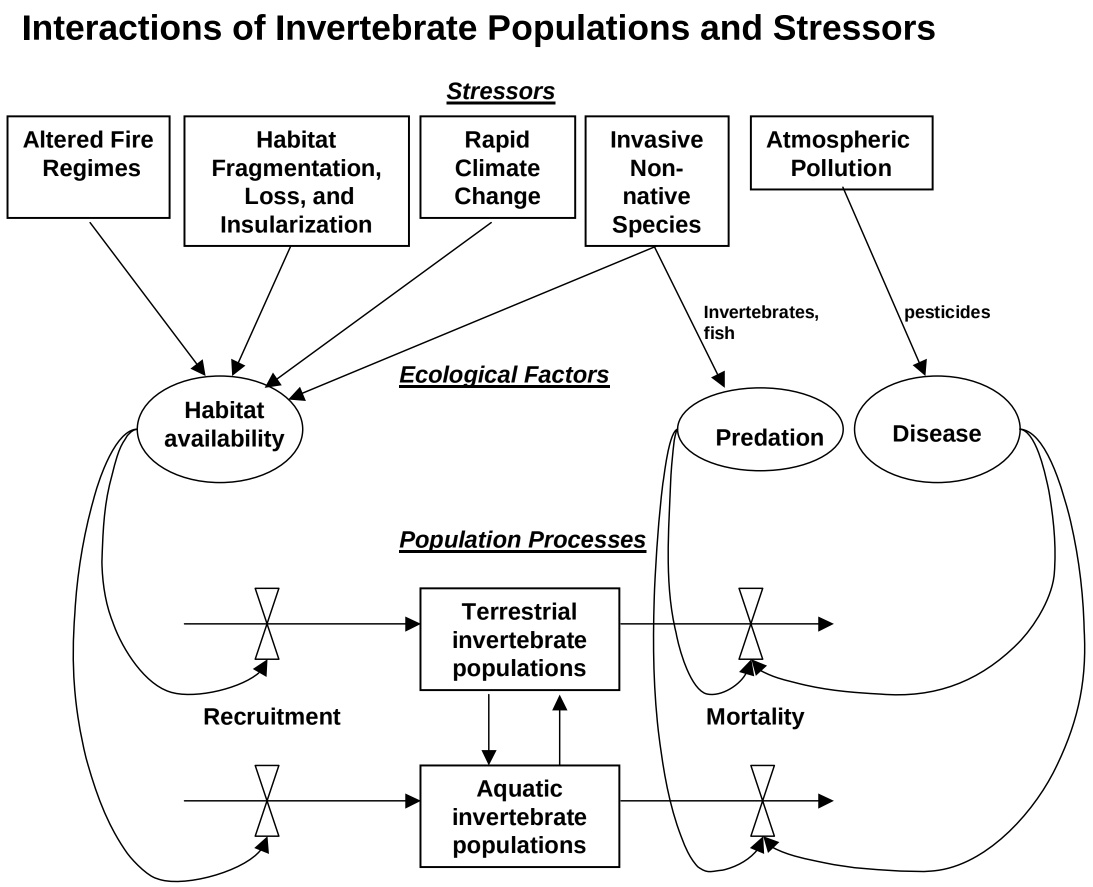


Figure I- 26. Main interactions of invertebrate populations and stressors. [Text to accompany this model will be done for the final Phase III report.

Future Development and Applications of Models

The Sierra Nevada Network will need to further develop conceptual models for the following purposes as protocols are developed and implemented, monitoring results need to be analyzed and interpreted, and the information must be shared with a variety of audiences:

- Outreach/communication: Attractive, simple pictorial models that explain focal systems and relationships of components and drivers for interpretive applications, general audiences, and perhaps, web pages.
- Information Interpretion/Gap Identification: complete models that elaborate more detailed relationships among components and drivers, capture improved understanding from on-going research and monitoring projects, and identify specific gaps in understanding in various systems.
- Prediction: Predictive models that use actual data to identify areas most sensitive to climatic change, most vulnerable to non-native plant invasions, or most affected by nitrogen deposition and ozone pollution.
- Simulation and analysis: Mathematical, statistical, or null models that predict patterns of species diversity, niche overlap, and species co-occurrence. Some networks in the NPS are beginning to use modeling simulation programs such as EcoSim (Gotelli and Entsminger 2006) to examine critical vectors such as species diversity.

The Network will need to consider modeling capability in its development of university partnerships and long-term network staffing, as conceptual and predictive modeling will be an integral part of monitoring program development, data analysis and interpretation, and communication and outreach.

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